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INVESTIGATIONS OF AN ELECTRICAL GLOW DISCHARGE,
WHEN INSERTED IN SUPERSONIC AIRFLOW,
TO DETERMINE ITS DEPENDENCE ON PRESSURE AND VELOCITY

by

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Master of Science

THESIS
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INVESTIGATIONS OF AN ELECTRIC OIL DISCHARGE,
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SUMMARY

It has been found in this preliminary investigation that an electrical glow discharge from a sharp point, when inserted in supersonic airflow ($M = 1.0$ to $M = 3.0$) is sensitive to the following conditions.

1. The glow current is definitely pressure sensitive at supersonic velocities.
2. Any Mach number change from $M = 1$ to $M = 3$ effects the glow current.
3. A greater voltage is required to maintain a given current for larger electrode spacings, a larger size wire, and a positive wire polarity.
4. Platinum wire of 0.003-inch minimum diameter could be used in this investigation because any smaller size wire bent when it was inserted in supersonic airflow.
5. Current flow from 10 to 80 microamperes gives enough glow discharge for this experiment ($M = 1.0$ to $M = 3.0$).
6. The shape of the plate and the material from which it is made effect the current flow.
7. The glow changes in size with changes in Mach number.
8. The glow changes in size with change in static pressure.
9. This device adapts itself for use as a static pressure measuring instrument and possibly as a Mach number recorder.

SUMMARY

It has been found in this preliminary investigation that an electrical glow discharge from a sharp point, when inserted in supersonic air ($M = 1.0$ to $M = 3.0$) is sensitive to the following conditions.

1. The glow current is definitely pressure sensitive at supersonic velocities.
2. Any Mach number change from $M = 1$ to $M = 3$ effects the glow current.
3. A constant voltage is sensitive to changes in given current for larger electrode spacings, a larger size wire, and a positive wire polarity.
4. Filament size of 0.003-inch minimum diameter could be used in this investigation because any smaller size wire would have been inserted in supersonic air.
5. Current flow rate in an air-water-glycerine mixture flow discharge for this experiment ($M = 1.0$ to $M = 3.0$).
6. The shape of the glow from the electrode tip when it is at right angles to the flow.
7. The glow current is also affected by the shape of the electrode.
8. The glow current is also affected by the shape of the electrode.
9. The glow current is also affected by the shape of the electrode.
10. The glow current is also affected by the shape of the electrode.

INTRODUCTION

Frank David Werner¹⁾ in his investigation of the possible utilization of an electrical glow discharge as a means for measuring airflow characteristics, found that the glow current from a sharp point is markedly pressure sensitive, somewhat dependent upon velocity, slightly dependent upon humidity, and apparently not dependent upon ordinary temperatures. His investigation was made through a velocity range from zero to 400 feet per second or a Mach number range of from zero to about 0.4.

The primary endeavor in the writer's investigation was to make a preliminary exploration to determine if such a glow would function at all in supersonic airflow, to design apparatus with which an electrical glow discharge from a sharp point could be studied, and also to determine if the glow is pressure or velocity dependent at Mach numbers greater than one. The Mach number range used in this investigation was from 1.0 to 3.0. The facility in which this investigation was carried out was constructed by the writer and Lt. Cdr. F. X. Timmes (graduate student) at the University of Minnesota Aeronautical Laboratories at the Rosemount Research Center, Rosemount, Minnesota.

Since this is the first time an electrical glow discharge from a sharp point has been inserted in supersonic airflow to investigate its dependence on pressures and Mach numbers, it is to be expected that the results obtained will have some experimental errors because of inadequate instrumentation and should be used only as a

guide for later and more elaborate studies. Experience in designing and using equipment to make this investigation should lead to the development of more accurate instrumentation, and to the elimination of some of these errors. However, the general trend of dependence upon Mach number and pressure of the electrical glow discharge from a sharp point will be shown in this investigation.

For this study it was decided to construct a special small size wind tunnel instead of using any of the University's full-scale tunnels. The reason for this decision was the necessity for more flexibility during investigations even though the accuracy of ultimate results may be lowered. Since this was the first use of the sharp point glow discharge in supersonic airflow, many adaptations were more convenient in this setup than in the full-scale tunnel. It is logical that the ultimate check of the data obtained in this tunnel would have to be made in a full-scale tunnel, but that step is beyond the scope of this paper. A single step attempt to use the needle in a full-scale tunnel is shown in the appendix.

The writer is grateful to Professor John D. Akerman for his advice and general direction of the research. Mr. Frank D. Werner was very helpful in the actual design of all the electrical equipment. Professor J. W. Braithwaite was of great assistance in the design and construction of the supersonic wind tunnel.

Guide for later and more elaborate studies. Experience in designing and using equipment to make this investigation should lead to the development of more accurate instruments.

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For this study it was decided to construct a

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sults may be lower. Since this was the first use of

the sharp point glow discharge in supersonic studies,

many assumptions were made concerning its use which were

to the full-scale tunnel. It is hoped that the others

found of the data obtained in this tunnel will have to

be made in a full-scale tunnel, but that that is beyond

the scope of this report. A similar case is made in the

the results in a full-scale tunnel is known in the

University.

of which is (1) the results of the present work in

the full-scale tunnel and (2) the results of the present

work in the small size tunnel. The results of the present

work in the small size tunnel are shown in the figures

and the results of the present work in the full-scale

tunnel are shown in the figures.

METHODS

The Laval nozzle was made of lucite for two reasons: First, because of its transparency, through lucite it is possible to observe the electrical glow discharge at different Mach numbers and at different static pressures. Second, since lucite is a good insulator, there was no danger of a current flow to ground through the nozzle if a short occurred. Lucite has proved to be an excellent material to satisfy the above requirements.

The probes were designed to be strong enough so that they would not bend in supersonic airflow. Also, a coating of arcylold, which is a liquid plastic that hardens in about 48 hours, was used on each probe not only to give more rigidity but also to act as an insulator. The insulatory properties of the coating were essential, especially where the probes were close together, to avoid arcing downstream of the platinum wire. Care was taken not to coat the plate circuit nor the platinum wire with the liquid plastic. Arcylold proved to be an excellent insulator.

When the plate circuit was positive and the wire negative, measurable current readings were recorded. When the wire was positive and the plate negative, current readings were so small that the electronic equipment designed for these tests did not detect any current flow. Since measurable current readings were recorded when the wire was negative, this type of circuit was used to obtain

The level nozzle was made of Lucite for two

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there was no danger of a current flow to ground through

the nozzle if a short occurred. Lucite has proved to be

an excellent material to satisfy the above requirements.

The probes were designed to be strong enough

so that they would not bend in supersonic airflow. Also,

a coating of acrylic, which is a liquid plastic that

cures in about 45 hours, was used on each probe not

only to give more rigidity but also to act as an insulator.

The insulating properties of the acrylic were essential,

especially since the probe wires were exposed to it.

During initial operation at the piston wire. Data was

taken not to show the probe elements nor the piston wire

with the liquid acrylic. Acrylic proved to be an

excellent insulator.

From the 1000-psi pressure and 1000-psi and 1000

psi pressure, constant pressure readings were recorded

from the wire and position of the probe. Position of the

probe was determined by the position of the wire and

position of the probe. The probe was positioned at the

position of the probe. The probe was positioned at the

position of the probe. The probe was positioned at the

the electrical glow discharge current readings. The theory behind this phenomenon is explained extensively in the paper written by Frank David Werner¹).

The writer has found in this investigation that current readings were obtained up to 350 microamperes at high voltage settings. At these high voltages and currents the electrical glow discharge was almost at an arcing stage; therefore, erratic current readings resulted at this high voltage. For this reason, lower current readings were used in the magnitude of from 60 to 80 microamperes. Enough points were recorded at these lower currents to plot smooth curves as are shown in Figures 2 through 6. From this it can be concluded that the use of lower current will give more stable readings and will give more accurately the trend of events under investigation.

The electronic equipment was designed to give from zero to 10,000 volts positive and from zero to 10,000 volts negative. These two circuits could then be connected in a series to give a range of from zero to 20,000 volts. It was not necessary to use more than 10,000 volts; therefore, it was not necessary to connect the two circuits together. The positive voltage supply was used throughout the entire investigation. The positive lead was connected to the plate circuit which also acted as the static probe while the ground (shield

The electrical glow discharge current readings. The theory behind this phenomenon is explained extensively in the paper written by Frank David Womery).

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that current readings were obtained up to 350 microamperes at high voltage settings. At these high voltages and currents the electrical glow discharge was almost at an active stage; therefore, erratic current readings resulted at high voltages. For this reason, lower current readings were used in the magnitude of from 50 to 100 microamperes. Through these readings it was found that the discharge is a glow discharge and not a spark discharge. It was found that the current readings were in good agreement with the readings obtained by the use of a standard ammeter and a standard resistor. The results of the investigation are given in the following table.

Investigation

The electrical glow discharge was obtained at five (5) voltages, 10, 20, 30, 40, and 50 volts. The current readings were obtained at each of these voltages. The results of the investigation are given in the following table.

of co-ax cable) of the circuit was connected to the probe holding the 0.003-inch platinum wire.

of co-ax cable) of the circuit was connected to the

probe holding the 0.003-inch platinum wire.

EQUIPMENT

Figure 31 shows the wind tunnel nozzle, the manometer board, the electrical equipment, and the probes. Figure 25 is a drawing, to scale, of the wind tunnel. Figure 26 is a scale drawing of the Laval nozzle blocks. Figures 27, 28, and 29 are diagrams of the electrical equipment.

The wind tunnel was supplied with a continuous flow of dry air from a 225-pound-per-square-inch storage tank of 1750 cubic foot capacity. The high pressure air leaves the tank through a 1-inch high pressure steel pipe. A 1-inch gate valve was used to control the air leaving the high pressure storage tank. The air enters the stagnation chamber of the wind tunnel through a 2-inch pipe. A 2-inch globe valve was installed in the 2-inch pipe line for use as a throttling valve. Stagnation pressures in the stagnation chamber were maintained by adjusting the 2-inch throttling valve.

A total head pressure gage was designed as shown in Figure 25. It consisted of a 1/4-inch steel pipe which held a hypodermic needle. This pipe was placed in the stagnation chamber as shown in the scale drawing of the wind tunnel (Figure 25). One end of this steel tube was plugged while the other end was connected to a pressure gage with a scale from zero to 100 pounds per square inch. It was found that this gage gave pressure readings accurate to within one percent of their correct value.

A standard type mercury manometer was constructed and used throughout this investigation to measure static pressure. Figure 31 shows this manometer as it was used to measure static pressures.

Figure 25 shows the bell-mouth entrance to the nozzle. This bell-mouth, made of hydrostone, proved to be very satisfactory. No cracking or chipping of the bell-mouth was noticed at the completion of this investigation.

Figure 26 is a scale drawing of the Laval nozzle blocks. The blocks and side plates were made of lucite and were designed to give a Mach number from 1.0 to 3.0, but a manufacturing error was made which gave a slightly different Mach number. This difference is shown in Figure 1. It can also be seen in Figure 1 that the experimental Mach numbers are slightly less than the theoretical Mach numbers at the same positions in the nozzle, but still gave satisfactory Mach numbers for $M = 1.0$ to $M = 3.1$.

The probes, as shown in Figures 30 and 33, were made of 1/4-inch steel tubing. The static probe also acted as the plate of the circuit. A 1/16-inch brass tube was inserted in the upstream end of the static probe. A static hole was drilled in this brass tube 8 diameters from the upstream end. The upstream end of the 1/16-inch brass tube was closed by silver solder and ground to a very fine point. A 1/16-inch solid steel rod was inserted in the upstream end of the glow probe that held the

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static pressure. Figure 3 shows this manometer as it is used throughout this investigation to measure

...of the ... of the ...

Figure 2 shows the bell-mouth entrance to the

mouth. This bell-mouth, made of hydrotalcite, proved to

and to provide to patients an accurate picture of

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and were assigned to five 1000-hour groups (1000, 2000, 3000, 4000, and 5000 hours).

and a number of other groups were also active in the area.

of the same kind as the one in the first case. This difference is shown in Figure 1.

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platinum wire. This upstream end of the solid steel rod was also ground to a very fine point. The 0.003-inch platinum wire was soldered to the upstream sharp end of the steel rod.

Both probes were coated with arcyloid which is a liquid plastic that hardens in about 48 hours. These probes were mounted in lucite holders that were fastened to the probe support. The probe support could be moved back and forth on a steel track, thus enabling the probes to be set at any position desired in the nozzle. Figure 32 shows the probe support and the track on which it could be moved.

The electronic equipment was designed in two separate parts. The circuit for part one is shown in Figure 28. This circuit produced a negative voltage of from zero to 10,000 volts. The circuit for part two is shown in Figure 29. This second circuit produced a positive voltage of from zero to 10,000 volts. Voltmeter and ammeter circuits (Direct Current) were designed as shown and were used to measure currents in microamperes and voltages. All voltmeter and ammeter readings are accurate to within 5 percent of their actual value. Both circuits were installed in the same panel as shown in Figure 31.

TEST PROCEDURE

The static probe, which also acted as the plate circuit of the electrical glow discharge, was inserted in the nozzle at 0.71-inch from the throat with the static hole just opposite the 0.71-inch position. At this position in the nozzle runs were made for different Mach numbers. The stagnation pressure was changed through a range of values to determine the stagnation pressure that produced the approximate theoretical Mach number in the nozzle at the 0.71-inch position. At positions of 1-inch, 2, 3, and 4 inches downstream the same procedure as described above was followed. A curve of the results is shown in Figure 1.

It was found that stagnation pressures of 25, 30, and 40 pounds per square inch gage gave a Mach number of 2.08 at the 1-inch position. Stagnation pressures of 40, 50, and 60 pounds per square inch gage gave a Mach number of 2.44 at the 2-inch position. The 3 and 4-inch positions were probed in the same manner, and Mach numbers of 2.8 and 3.1 were established. Stagnation pressures of 70, 80, and 90 pounds per square inch gage were used at the 3-inch position, and 90, 94, and 100 pounds per square inch were used at the 4-inch position. It was found that below certain stagnation pressures the Mach number at any position could not be obtained. Since the nozzle did not have a diffuser attached to its exit, these high stagnation pressures are to be expected and check very

TEST PROCEDURE

The static probe, which also acted as the static circuit of the electrical flow discharge, was inserted in the nozzle at 0.71-inch from the throat with the static hole just opposite the 0.71-inch position. At this position in the nozzle runs were made for different Mach numbers. The stagnation pressure was changed through a range of values to determine the stagnation pressure that produced the approximate theoretical Mach number in the nozzle at the 0.71-inch position. At positions of 1-inch, 2, 3, and 4 inches upstream from the same procedure as described above was followed. A curve of the results is shown in Figure 1.

It was found that stagnation pressures of 25, 30, and 40 pounds per square inch gave a Mach number of 2.0 at the 1-inch position. Stagnation pressures of 40, 50, and 60 pounds per square inch gave a Mach number of 2.5 at the 2-inch position. The 2 and 4-inch positions were found to be the same, and Mach numbers of 2.0 and 2.5 were obtained. Stagnation pressures of 70, 80, and 90 pounds per square inch gave Mach numbers of 3.0 and 3.5 at the 3-inch position. At the 4-inch position, stagnation pressures of 70, 80, and 90 pounds per square inch gave Mach numbers of 3.0 and 3.5.

Figure 1 shows the results of the test procedure. The curve shows the stagnation pressure required to produce a given Mach number at a given position in the nozzle. The curve is a smooth curve, and the data points are well represented by a single curve.

closely to those given in reference 5.

After the static probe Mach number calibration (Figure 1) was made at the various positions in the nozzle, the probe that held the small platinum wire was placed in position. The 0.003-inch platinum wire on this probe was lined up just opposite the static hole in the static probe. With the wire and plate at 0.25-inch spacing between them inserted in the nozzle at the various positions, runs were made as described in the preceding paragraph. Using this configuration, it was found that the same static pressures as obtained with the static probe alone were obtained at any position using corresponding stagnation pressures, thus showing no effect of the glow probe on static pressure and Mach number at locations under investigation.

With the probe spacing of 0.25-inch and the stagnation pressures necessary to produce the Mach number at any given position, runs were made at the various positions in the tunnel. The same procedure was followed for a 0.125-inch spacing. Ammeter and voltmeter readings were recorded during each run.

Since runs were made as rapidly as possible, it was assumed that for any run the temperature remained constant. Also, dry air (-400 F.) was used throughout the investigation.

A vacuum jar was used to determine pressure effect on the glow discharge at zero Mach number. The

closely to those given in reference 2.

After the static probe Mach number calibration

(Figure 1) was made at the various positions in the

nozzle, the probe that held the small platinum wire was

placed in position. The 0.003-inch platinum wire on this

probe was lined up just opposite the static hole in the

static probe. With the wire end plate at 0.25-inch

spacing between them inserted in the nozzle at the various

positions, runs were made as described in the preceding

paragraph. Using this calibration, it was found that

the same static pressure is obtained with the static

probe alone were obtained at any position when correspond-

ing static pressure, thus showing no effect of the

flow probe on static pressure and Mach number at locations

under investigation.

With the probe spacing at 0.25-inch and the

static probe pressure directly in position the Mach number

at any given position, runs were made at the various

positions in the nozzle. The same procedure was followed

for the 0.003-inch probe spacing and very good agreement

was obtained with the static probe.

Figure 2 shows the static pressure distribution

and Mach number in the nozzle at the various positions

investigated. The static pressure distribution is shown

in Figure 3 and the Mach number distribution in Figure 4.

The static pressure distribution is shown in Figure 3 and the Mach number distribution in Figure 4.

plate and wire used in the vacuum jar were made of the same material and were the same size. Various absolute pressures were maintained in the jar, and ammeter and voltmeter readings were obtained. Dry air, often ventilated to avoid ionization, was used in the vacuum jar. Figure 2 gives data obtained from this test.

plate and wire used in the vacuum jar were made of the same material and were the same size. Various absolute pressures were maintained in the jar, and ammeter and voltmeter readings were obtained. Dry air, often vented to avoid ionization, was used in the vacuum jar. Figure 2 gives data obtained from this test.

TEST DATA (EXPLANATION OF)

Figure 1 shows the Mach number versus the distance along the nozzle. The Mach number was determined by a static probe connected to a mercury manometer. The stagnation pressure was read directly from a pressure gage. If the stagnation pressure, the static pressure, and the barometer reading are known, Mach number can be easily determined. Isentropic flow was assumed upstream and downstream (but not through) the normal shock wave.

Figures 1 through 7 give microamperes versus volts at various Mach numbers ranging from zero to 3.1. The space between the plate and the wire was 0.25-inch. These curves show that the glow discharge is definitely dependent on pressure.

Figures 8 through 12 give absolute pressures versus volts at various current flows. The data for these curves were obtained from the microamperes versus volts curves (Figures 1-7).

The final curve, Figure 13, shows the effect of Mach number. Here microamperes versus volts at constant absolute pressure were plotted. After studying these curves, it can be readily seen that the glow discharge is velocity dependent. It can be seen that all curves from $M = \text{zero}$ to $M = 2.8$ have the same general trend, but the $M = 3.1$ curve is different. This is probably due to experimental errors and to poor supersonic airflow at the 4-inch position. Nevertheless, all the

TEST DATA (EXPLANATION OF)

Figure 1 shows the Mach number versus the distance along the nozzle. The Mach number was determined by a static probe connected to a mercury manometer. The stagnation pressure was read directly from a pressure gage. If the stagnation pressure, the static pressure, and the measured velocity are known, Mach number can be easily determined. Isentropic flow was assumed upstream and downstream (but not through) the normal shock wave. Figure 1 through 7 give characteristics versus static pressure at various Mach numbers ranging from 0.5 to 2.5. The space between the plate and the wire was 0.25-inch. These curves show that the flow character is definitely independent of pressure.

Figure 8 through 10 give measured pressure versus static pressure at various Mach numbers. The data for these curves were obtained from the characteristics versus static pressure (Figures 1-7).

The flow shown in Figure 11 shows the static pressure distribution along the nozzle. The static pressure was measured by a static probe connected to a mercury manometer. The static pressure was measured at various Mach numbers ranging from 0.5 to 2.5. The space between the plate and the wire was 0.25-inch. These curves show that the flow character is definitely independent of pressure.

curves show the same general trends and indicate that the Mach number has an effect on the electrical glow discharge.

The remaining curves, Figures 13 through 24, show test data under the same condition as above except that the spacing of the plate and wire was reduced to 0.125-inch. Again it can be seen that the electrical glow discharge is pressure and Mach number dependent. However, this time the Mach number curves did not plot in the same sequence. This is partly due to experimental errors, and it is expected that at the 0.125-inch spacing there is some airflow interference between the plate and the wire, even though it did not show up on the static readings. These curves, even though they don't follow in sequence, show a general trend which indicated that the glow discharge is dependent on Mach number.

Figure 34 shows a spark photograph of the nozzle blocks at a Mach number of zero. It can be seen that the channel walls are fogged up; this is due to poor glueing of the side plates to the nozzle blocks, indicating that the glue had run down the walls of the nozzle. The black heavy line below the channel is a tape measuring device for placing probes at exact position in the nozzle.

Figure 35 shows the same nozzle with supersonic airflow at a Mach number of 2.81. Shock waves at the 4-inch position can be seen. Also, at about the 4-inch position the flow starts to separate, and by the time it

curves show the same general trends and indicate that the Mach number has an effect on the electrical glow discharge. The remaining curves, Figures 13 through 24, show test data under the same condition as above except that the spacing of the plate and wire was reduced to 0.125-inch. Again it can be seen that the electrical glow discharge is pressure and Mach number dependent. However, this time the Mach number curves did not vary in the same sequence. This is partly due to experimental errors, and it is expected that at the 0.125-inch spacing there is some slight interference between the plate and the wire, even though it did not show up on the static readings. These curves, even though they don't follow in sequence, show a general trend which indicated that the glow discharge is dependent on Mach number. Figure 25 shows a spark photograph of the nozzle closure at a Mach number of zero. It can be seen that the channel walls are tapered up; this is due to poor glazing of the side plates to the nozzle body, indicating that the glue had run down the walls of the nozzle. The glow heavy line section and channel is a large converging device for pinching gases at exact position in the nozzle. Figure 26 shows two more nozzle exit photographs at Mach numbers of 0.1 and 0.2. These curves show that the glow discharge can be seen, and it is expected that the glow discharge is dependent on Mach number.

reaches the end of the nozzle it appears to have separated almost completely. Due to the cloudy sides of the channel nothing else can be seen.

Figure 36 shows the same nozzle block with supersonic airflow at a Mach number of 2.81, but this time the probes are inserted in the nozzle. The spacing between the plate and wire was 0.25-inch. Here it appears that the probes have helped the flow, but again due to reflection through the top wall of the channel and cloudy channel walls, little of importance can be seen. Even though the flow appears better with the probes inserted, the static probe manometer readings indicated that ^{at} the 4-inch position separation and turbulent flow exists.

Since this experimentation was the first exploration of the supersonic flow by means of sharp point glow discharge, the establishment of methods, trends, limitations, and possible expectations for this type of flow study was more important than finality of results. At the start of the investigation it was not possible to predict in which direction to concentrate and, therefore, a flexibility in general of instrumentation was more important than fine accuracy of any one item in particular, but even with this procedure, the accuracy of all test data is limited only by the type of instrumentation used and the accuracy with which it was read. Considering the type of gauges and electronic equipment used, an overall

accuracy of all test data is approximately 95 percent.

accuracy of all test data is approximately 95 percent.

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CONCLUSIONS AND RECOMMENDATIONS

It is concluded that an electrical glow discharge when inserted in supersonic airflow has the following characteristics:

1. The glow current is definitely pressure sensitive.
2. The glow current is dependent on velocity -- that is, any Mach number between $M = 1$ and $M = 3$ change effects the glow current.
3. A greater voltage is required to maintain a given current for larger electrode spacings, a larger size wire, and positive wire polarities.
4. Platinum wire 0.003-inch diameter could be used in this investigation because any smaller size wire bent when it was inserted in supersonic airflow.
5. Current flow from 10 to 80 microamperes gives enough glow discharge for this experiment.
6. The shape of the plate and the material from which it is made effect the current flow.
7. The glow changes in size with changes in Mach number.
8. The glow changes in size with change in static pressure.
9. This device adapts itself for use as a static pressure measuring instrument and possibly as a Mach number recorder.

The following recommendations are given below:

1. If lucite nozzle blocks are to be made for this tunnel, it is recommended that great care be taken in the gluing process to give clear and smooth walls.
2. Nozzle blocks should be made by the method of characteristics, thus eliminating the bad flow conditions encountered in the Laval nozzle.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that an electrical glow discharge when inserted in supersonic airflow has the following characteristics:

1. The glow current is definitely pressure sensitive.
2. The glow current is dependent on velocity -- that is, any Mach number between $M = 1$ and $M = 3$ change affects the glow current.
3. A greater voltage is required to maintain a given current for larger electrode spacings, a larger size wire, and positive wire polarities.
4. Titanium wire 0.003-inch diameter could be used in this investigation because any smaller size wire bent when it was inserted in supersonic airflow.
5. Current flow from 10 to 50 microamperes gives enough glow discharge for this experiment.
6. The shape of the pulse and the material from which it is made affect the current flow.
7. The glow changed in size with changes in each parameter.
8. The glow changes in size with changes in static pressure.
9. This device might be useful for use as a static pressure measuring instrument and possibly as a Mach number indicator.

The following two graphs are included as an appendix.

1. Graph showing the variation of glow current with Mach number.
2. Graph showing the variation of glow current with static pressure.

3. An extremely sensitive type of throttling valve be incorporated in the equipment to enable the operator to hold stagnation pressures more closely to the desired value.
4. An accurate means of measuring stagnation pressures be used. It is suggested that an electronic gage (strain gage) be used.
5. A mount holder for the probes should be designed so that it will give good accessibility to a change in spacing of plate and wire.
6. The two probes should be made of a strong insulating material, thus eliminating steel tubing and liquid plastic insulations.
7. A high voltage fuse should be used in the electronic equipment to avoid any voltage leakage and to protect the power supply.
8. A voltmeter and an ammeter circuit should be designed to measure the voltage and the current when the two power supplies are connected in series.
9. A tapered needle to give sharper point and enough strength to withstand air blast may be necessary and if it is not too expensive to manufacture, should be tried in the next experiments.

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4. An accurate means of measuring stagnation pressure be used. It is suggested that an electronic gage (strain gage) be used.

5. A mount holder for the probes should be designed so that it will give good accessibility to a change in spacing of plate and wire.

6. The two probes should be made of a strong insulating material, thus eliminating steel tubing and liquid plastic insulations.

7. A high voltage line should be used in the electronic equipment to avoid any voltage leakage and to protect the power supply.

8. A voltmeter and an ammeter circuit should be designed to measure the voltage and the current when the two power supplies are connected in series.

9. A tapered needle to give sharper point and enough strength to withstand air blast may be necessary and it is not too expensive to manufacture, should be tried in the next experiments.

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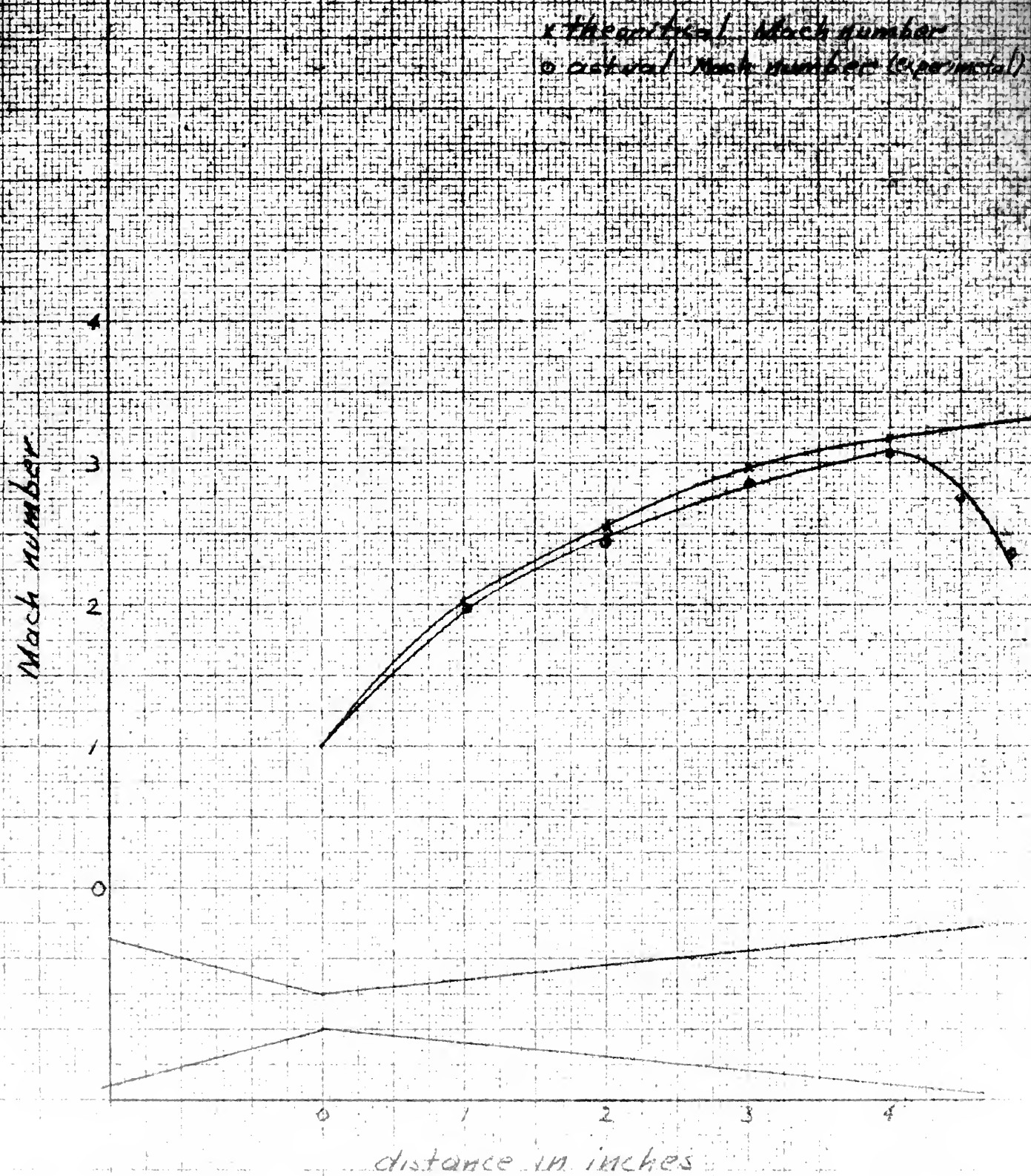


Fig-1-

Voltage VS Current for absolute Pressures
between 29.14 inches Hg and 4.12 inches Hg.

Mach number equal 0

Wire .003 platinum spacing .25 inches

Dry air

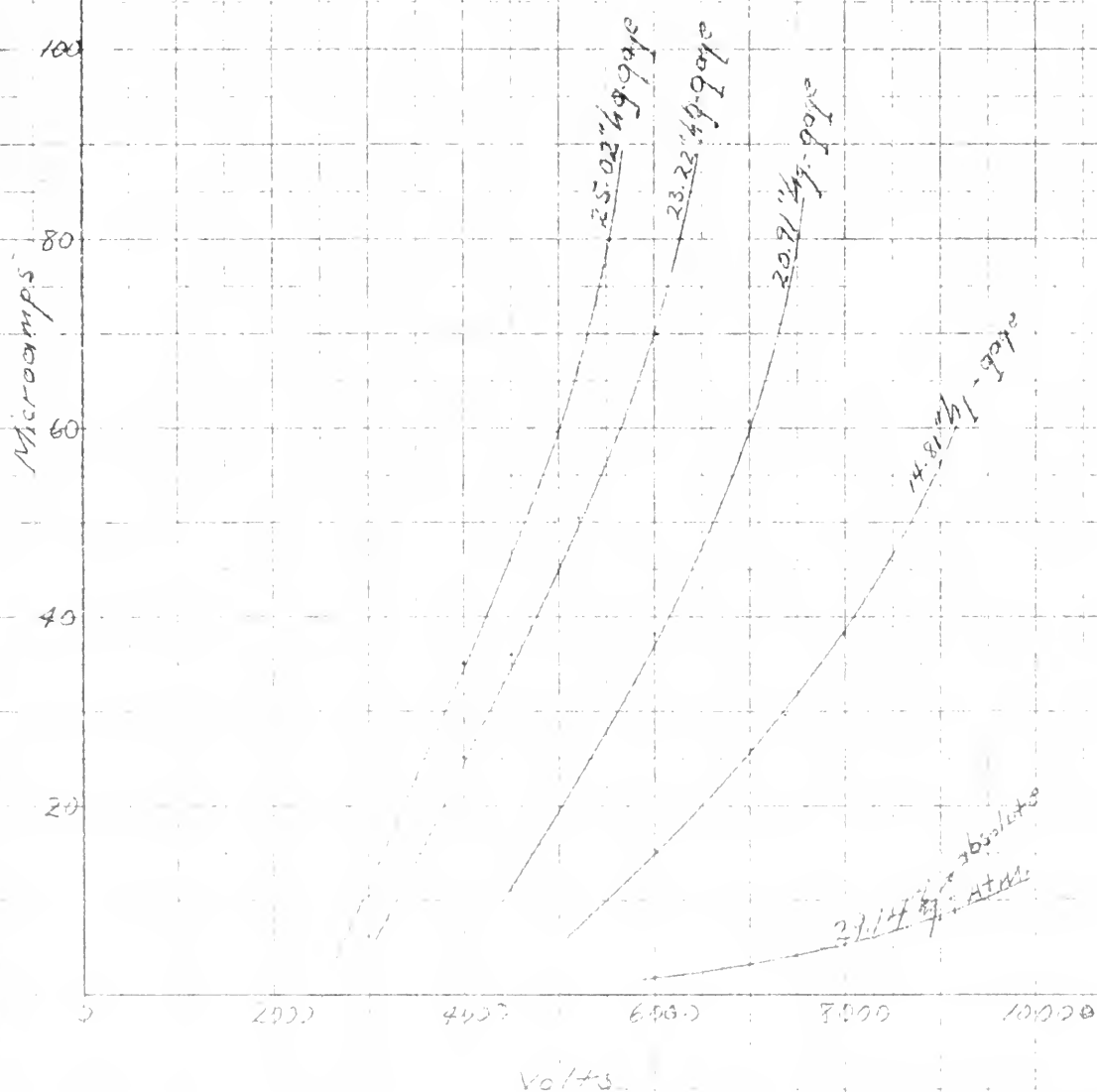


Fig. 2

Microamps V.S. Volts

Wire .003 ; spacing .25 inches

Position .71 inches in nozzle

Mach number 1.72

140 Stagnation pressure 21.0 $\frac{\text{lb}}{\text{in}^2}$ abs ; static probe 5.4 $\frac{\text{lb}}{\text{in}^2}$ abs
 " " 21.8 $\frac{\text{lb}}{\text{in}^2}$ abs ; " 4.3 $\frac{\text{lb}}{\text{in}^2}$ abs
 " " 27.8 $\frac{\text{lb}}{\text{in}^2}$ abs ; " 4.2 $\frac{\text{lb}}{\text{in}^2}$ abs

Microamps

120

100

80

60

40

20

21.0 $\frac{\text{lb}}{\text{in}^2}$
 21.8 $\frac{\text{lb}}{\text{in}^2}$
 27.8 $\frac{\text{lb}}{\text{in}^2}$

200 400 600 800 1000

Volts

Fig-3-

Microamps vs Volts

.003 wire

.25" spacing

1" position in nozzle

Mach number = 2.08

Stagnation pressure of 25# gage; static probe 10.3 #/sq in
 " " " 30# gage " " 9.15 #/sq in
 " " " 40# gage " " 7.15 #/sq in

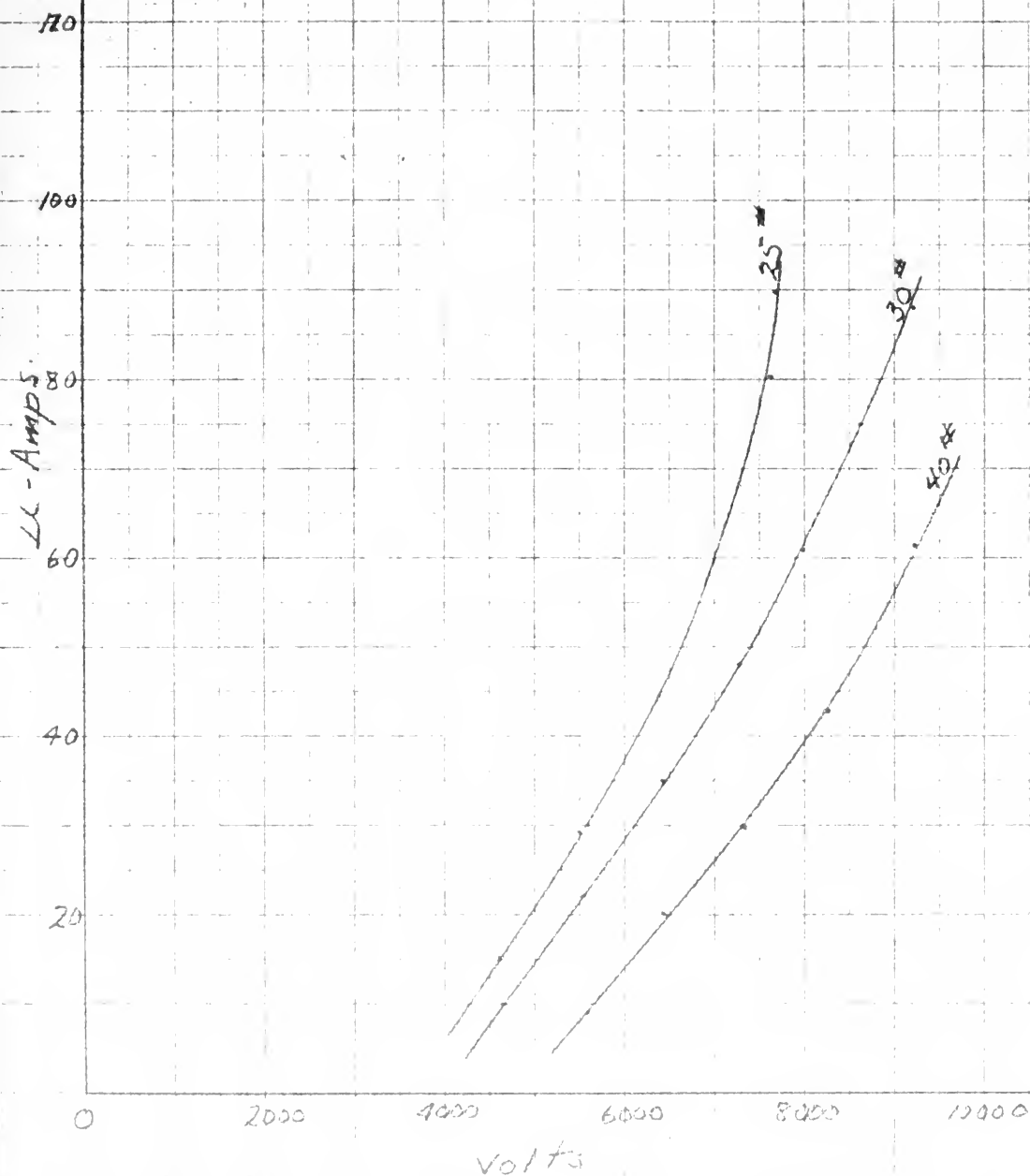


Fig-4



Microamps vs Volts

Wire - .003 platinum

Spacing - .25 inches

Position in nozzle 2"

Mach number = 2.44

Stagnation pressure of 40# gage; static probe 11.5# gage

50# gage; " " 10.2# gage

60# gage; " " 9.2# gage

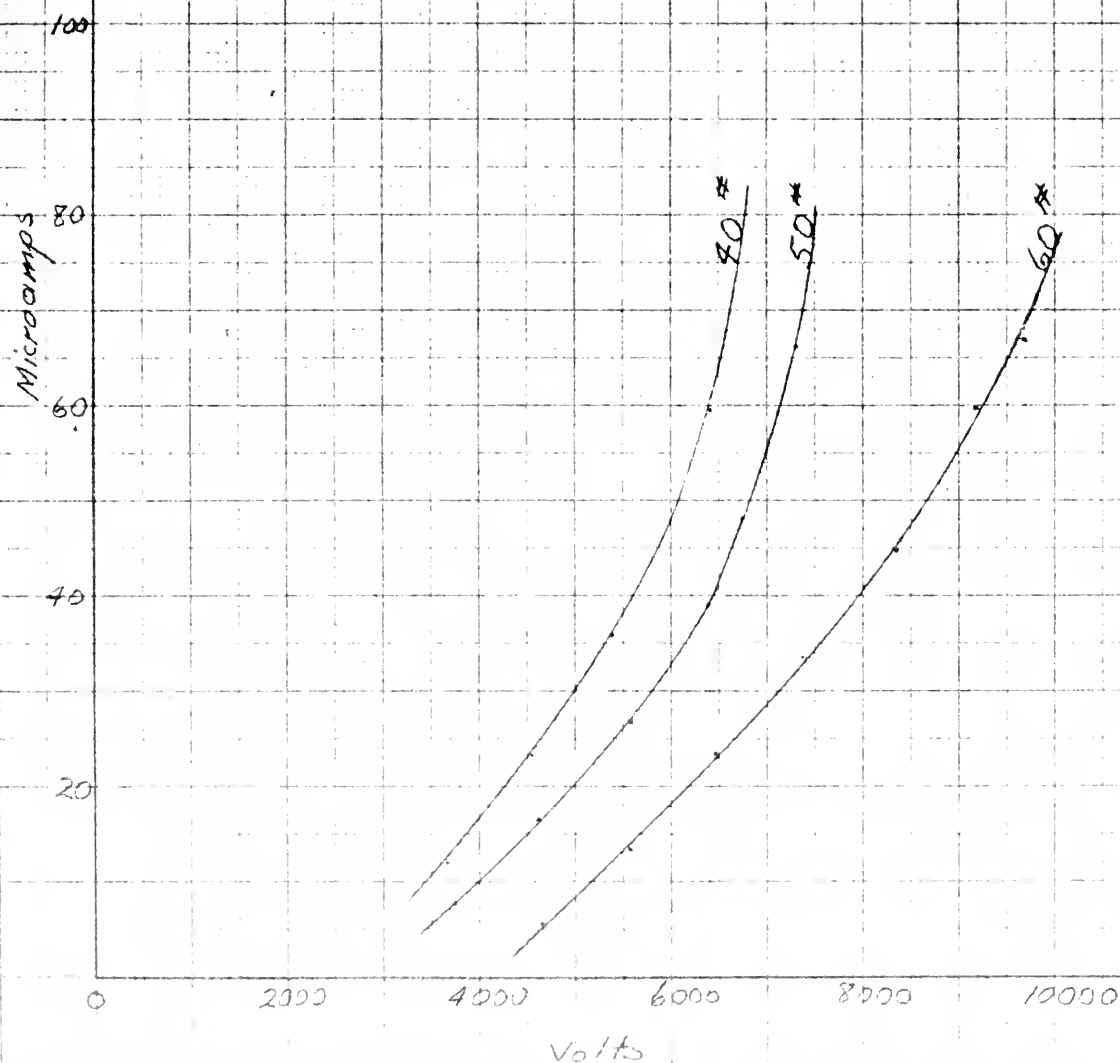


Fig-5-

Microamps vs Volts

Wire - .003 platinum

Spacing .25 inches

Position 3 inches from throat

Mach number 2.81

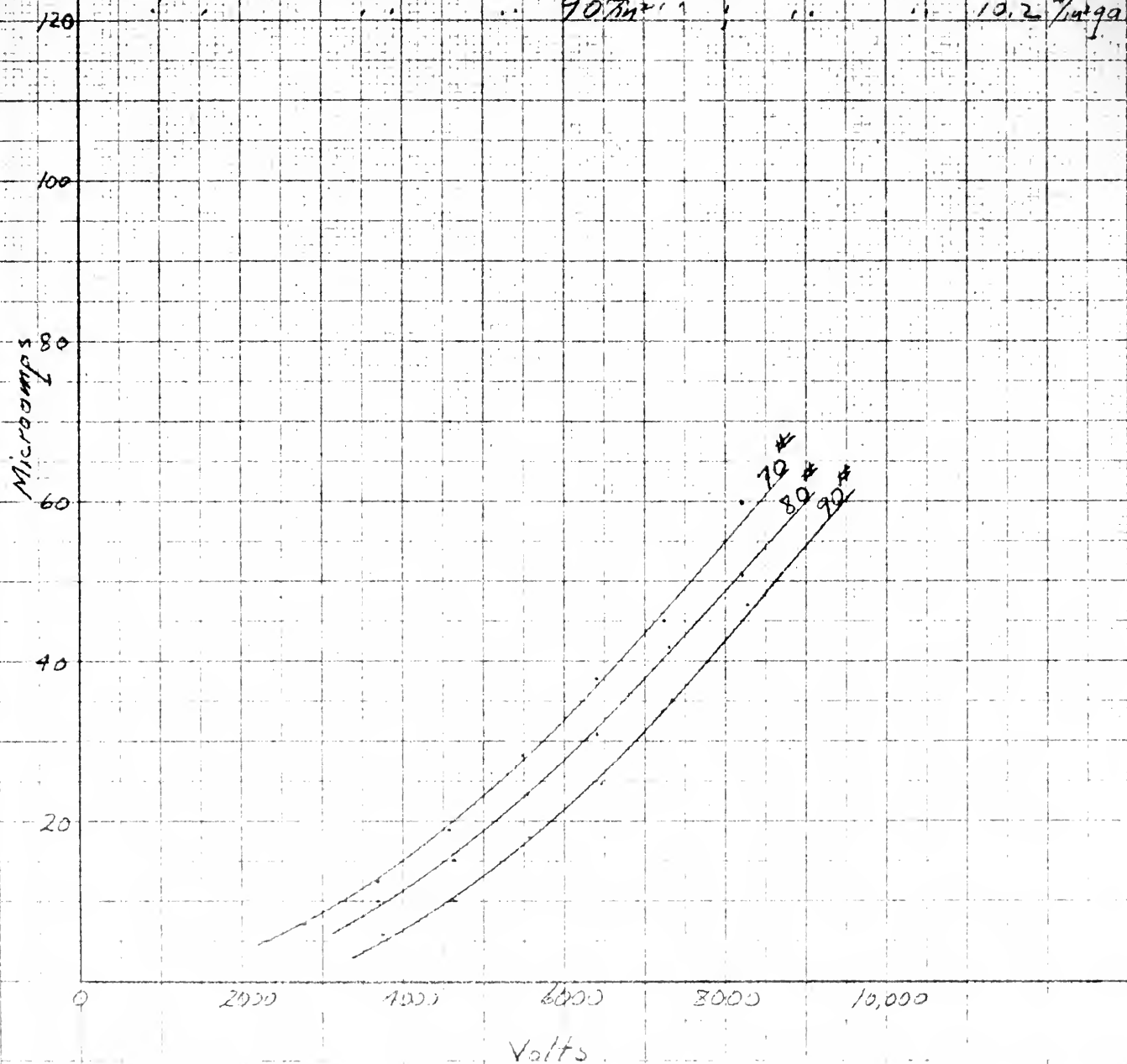
Stagnation pressures of 70th gage; Static probe 11.7 #/sq in.Stagnation pressure of 80th " " " " 11.0 #/sq in.Stagnation pressure of 90th " " " " 10.2 #/sq in.

Fig - 6 -

Microamps vs Volts

Wire .003 platinum

Spacing .25 inches

Position in nozzle 4"

Mach number = 3.1

Stagnation pressure	90 $\frac{\text{lb}}{\text{in}^2}$ gage	; static probe	12.4 $\frac{\text{lb}}{\text{in}^2}$ gage
"	94 $\frac{\text{lb}}{\text{in}^2}$	"	12.1 $\frac{\text{lb}}{\text{in}^2}$
"	100 $\frac{\text{lb}}{\text{in}^2}$	"	11.87 $\frac{\text{lb}}{\text{in}^2}$

Microamps

140

120

100

80

60

40

20

0

2000

4000

6000

8000

10000

Volts

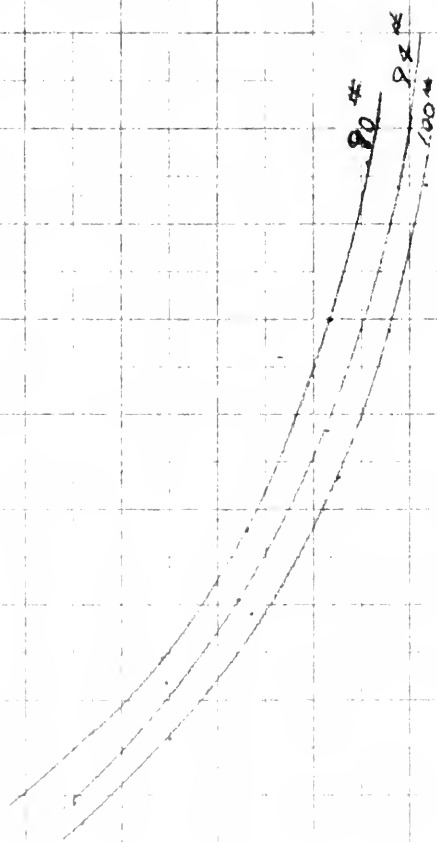


Fig-7-

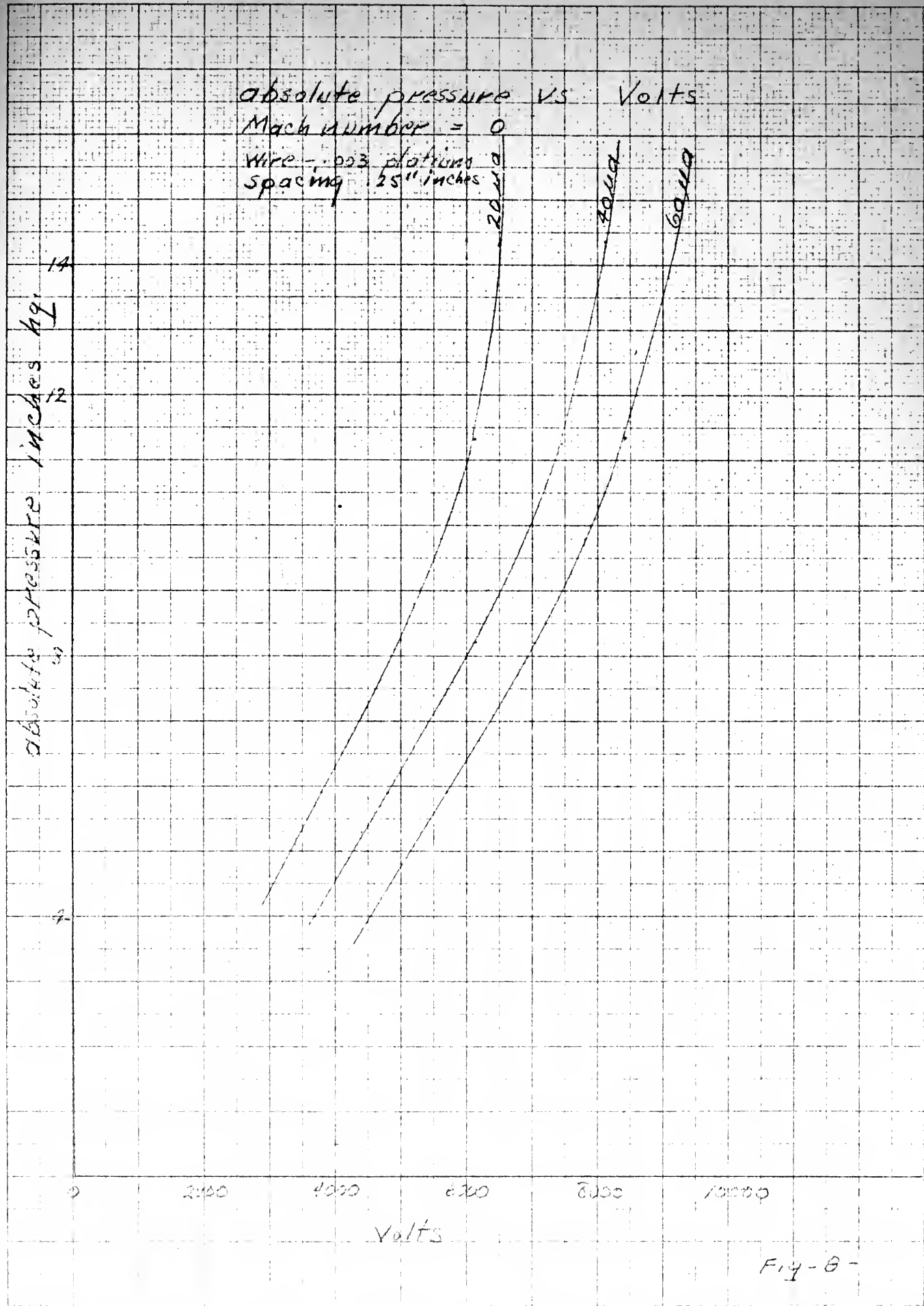


Fig-6-

absolute pressure vs Volts

Mach number = 2.08

Wire - .003 platinum
Spacing .25 inches

absolute pressure inches Hg.

20 Volts

40 Volts

60 Volts

0

2000

4000

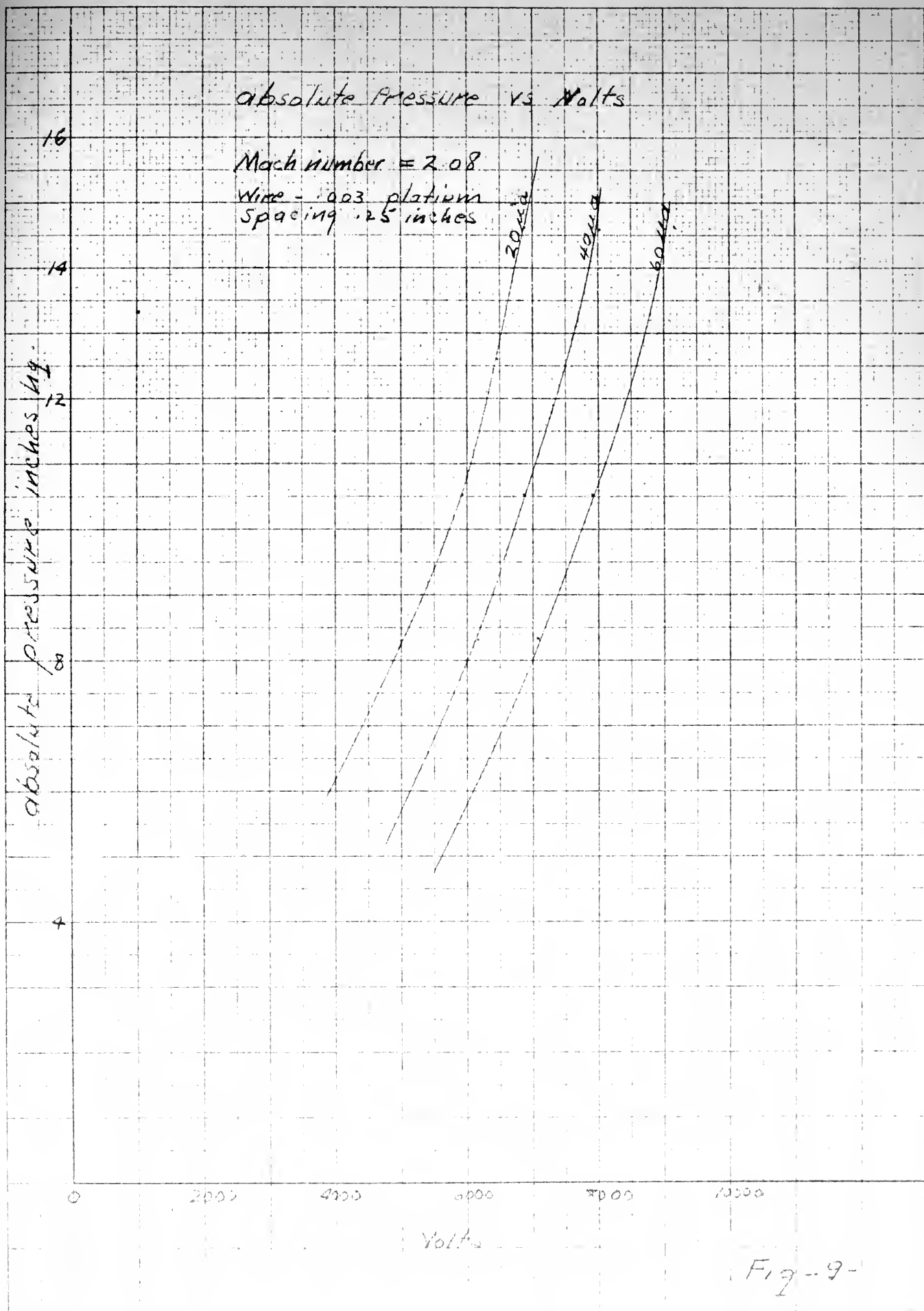
6000

8000

10000

Volts

Fig-9-



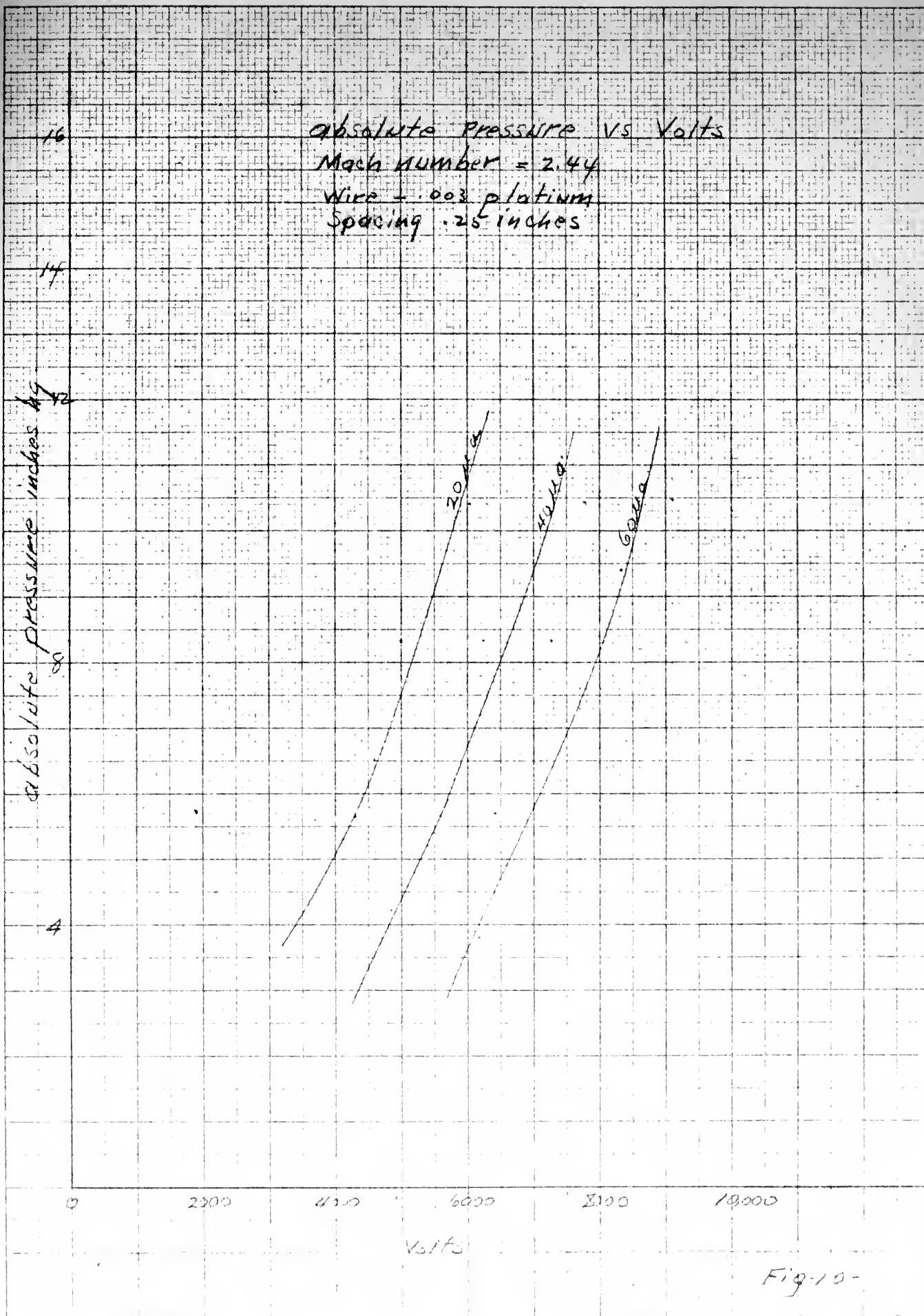


Fig-10-

Absolute Pressure vs. Volts

Mach number 2.81

Wire .003 platinum

Spacing .25 inches

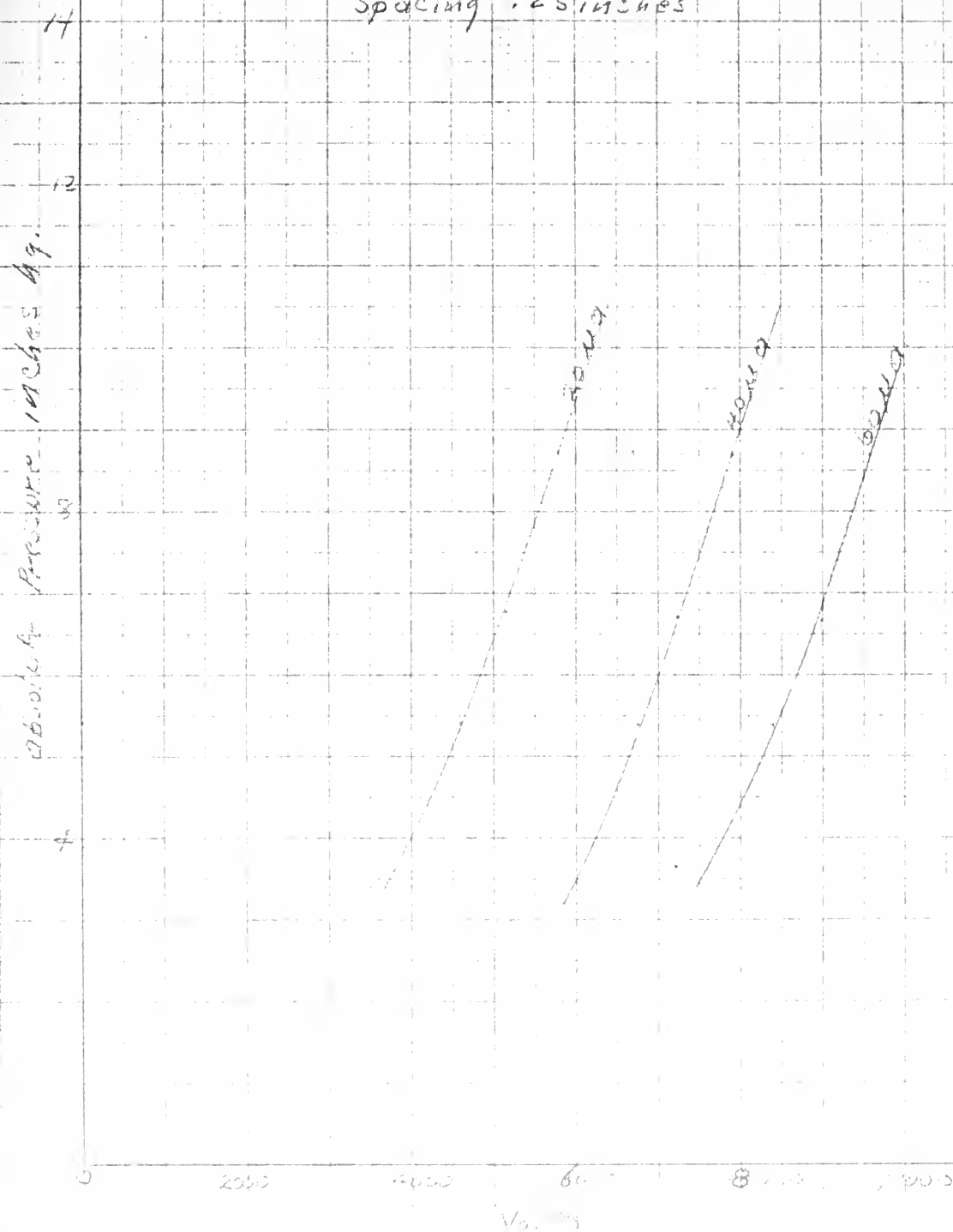


Fig. 11-

absolute pressure vs Volts
Mesh number 3.1
Wire .003 platinum
Spacing .25 inches

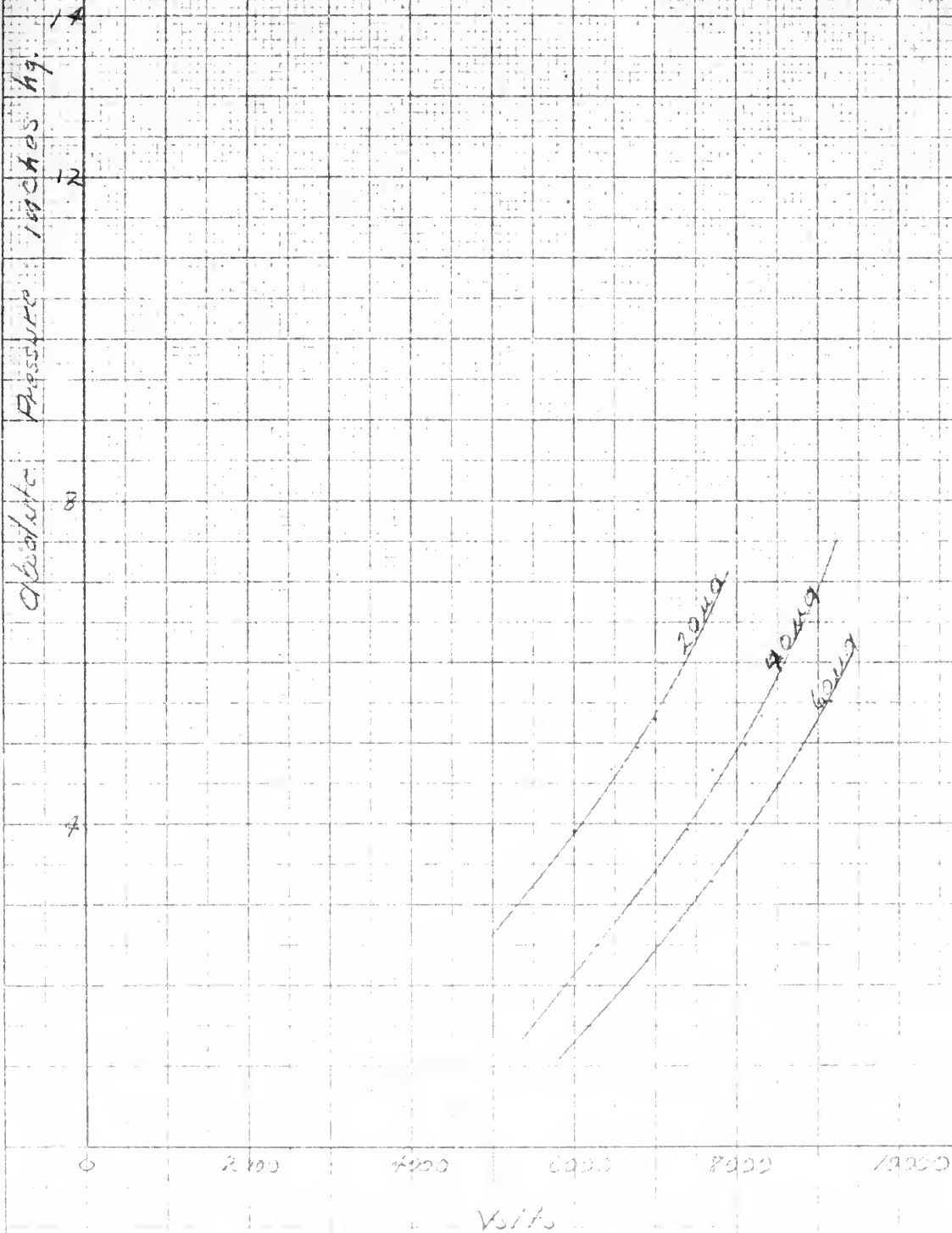


Fig-12.

Microamps vs Volts at const. obs. pressure
 absolute pressure = 5 inches hg.
 wire - .003 platinum
 spacing - .25 inches



Voltage vs Current for absolute pressures
between 29.14 inches Hg and 4.46 inches Hg.

Mask number equal 0

Wire .003 platinum ; spacing .125 inches

Dry air

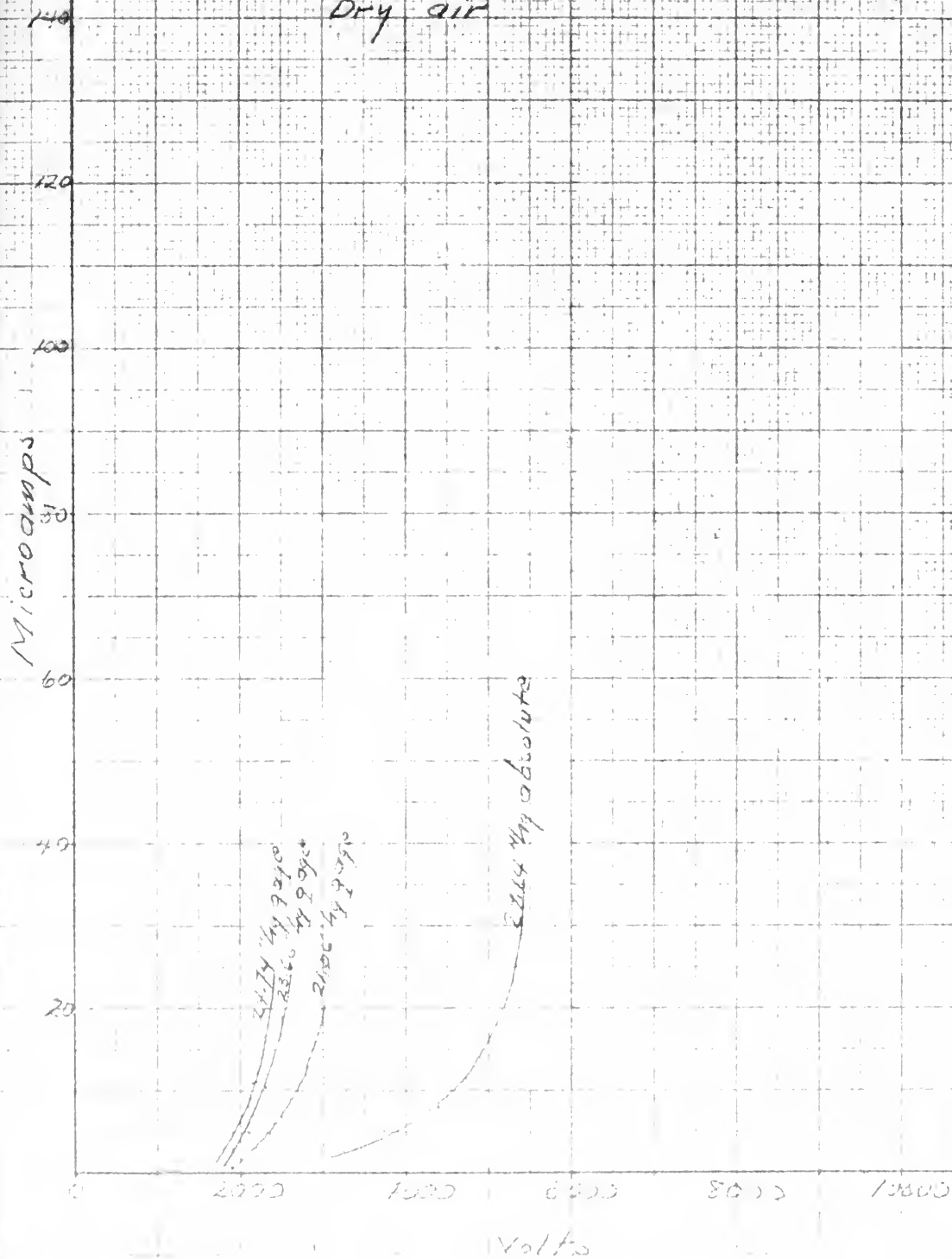
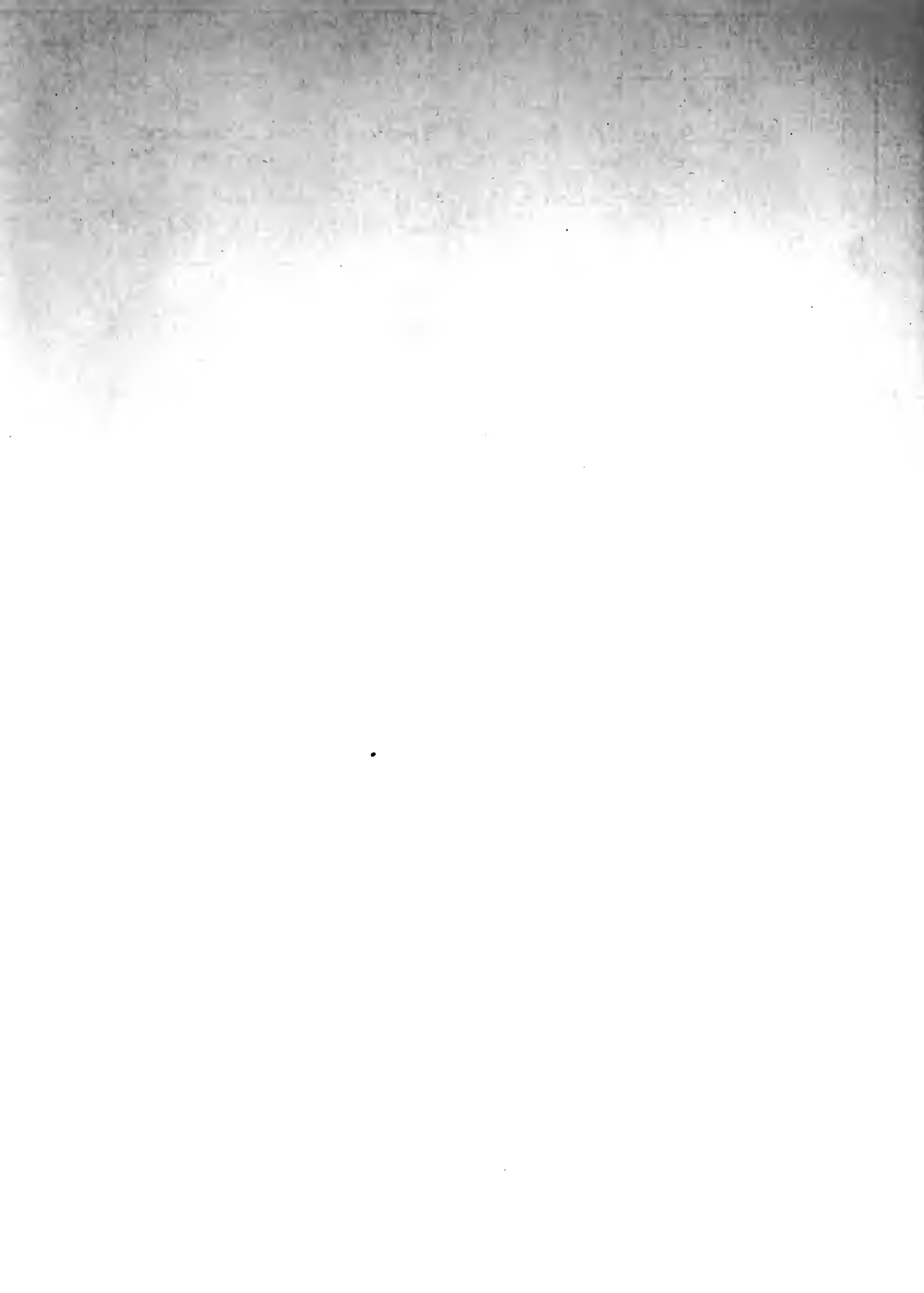


Fig -14-



Microamps vs. Volts

Wire .003 platinum spacing .125"

Position .6 inches in nozzle

Mach number 1.62

Stagnation pressure	21.9 $\frac{\text{lb}}{\text{in}^2}$	Static probe	4.94 $\frac{\text{lb}}{\text{in}^2}$ abs
"	21.2 $\frac{\text{lb}}{\text{in}^2}$	"	4.88 $\frac{\text{lb}}{\text{in}^2}$ abs
"	26.2 $\frac{\text{lb}}{\text{in}^2}$	"	6.51 $\frac{\text{lb}}{\text{in}^2}$ abs

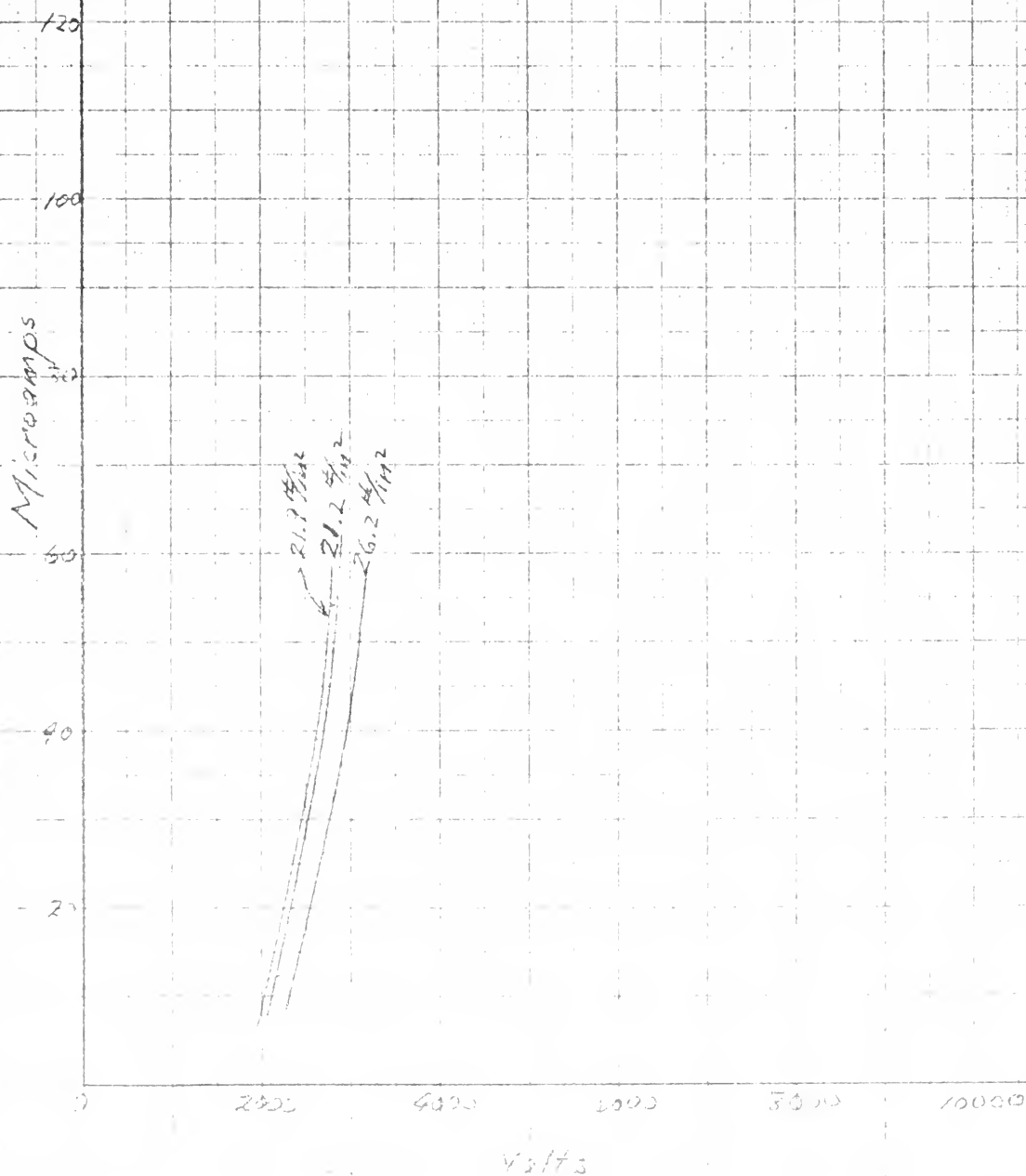


Fig-15-

Microamps VS Volts

Wire: .003 platinum

Spacing: .125"

Position in nozzle 1"

Mach number - 2.03

Stagnation pressure at 25 $\frac{\text{in}^2}{\text{in}^2}$ gage; probe (static) 10.3 $\frac{\text{in}^2}{\text{in}^2}$
 " 30 $\frac{\text{in}^2}{\text{in}^2}$ " " " 7.15 $\frac{\text{in}^2}{\text{in}^2}$
 " 40 $\frac{\text{in}^2}{\text{in}^2}$ " " " 7.15 $\frac{\text{in}^2}{\text{in}^2}$

Microamps

140

120

100

80

60

40

20

0

2000

4000

6000

8000

10000

Volts

Fig-16-

Microamps

Microamps vs. Volts

.003 wire platinum

.125" spacing

2" position in nozzle

Mach number 2.44

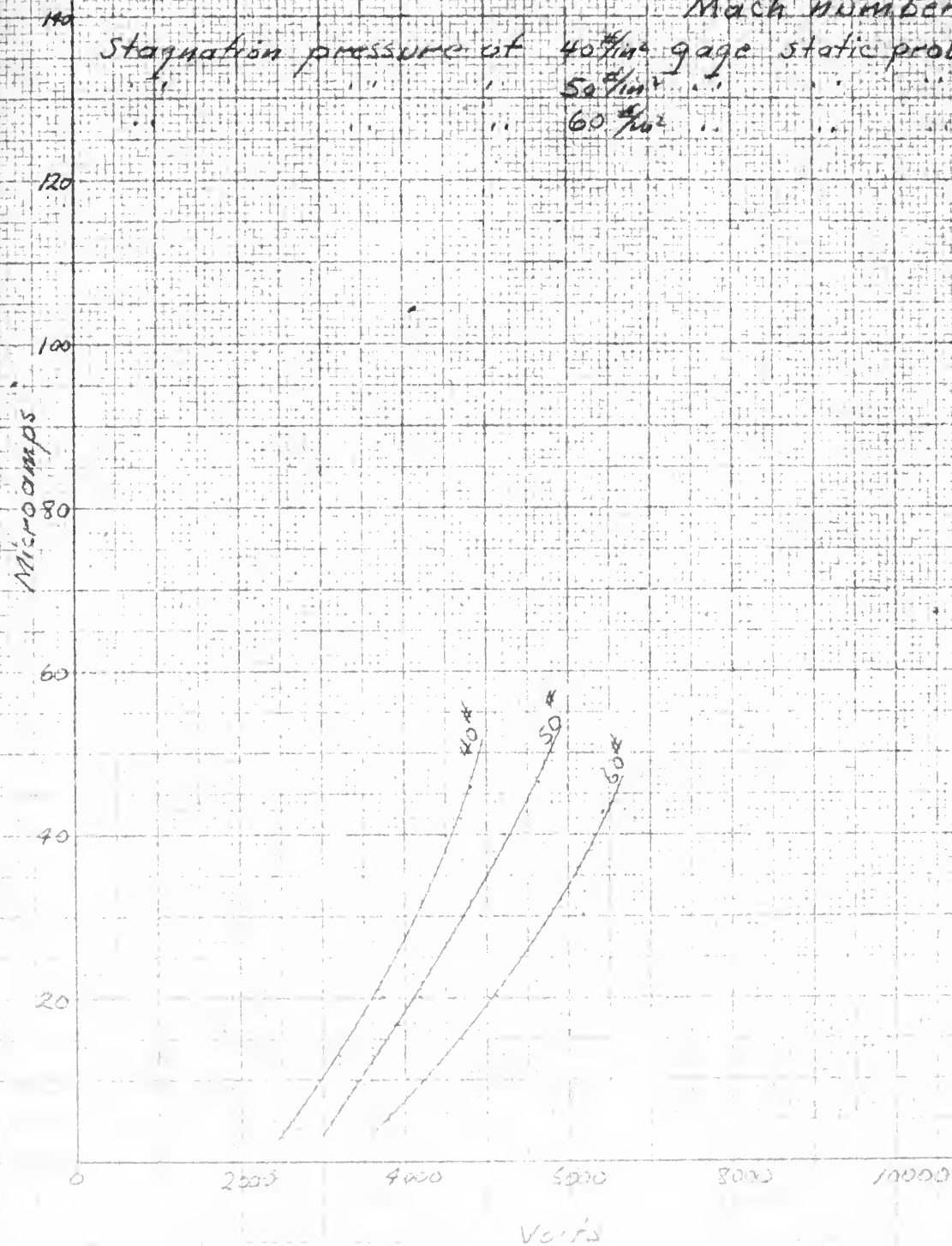
Stagnation pressure at 40 $\frac{\text{lb}}{\text{in}^2}$ gage static probe 11.5 $\frac{\text{lb}}{\text{in}^2}$ gage50 $\frac{\text{lb}}{\text{in}^2}$..10.2 $\frac{\text{lb}}{\text{in}^2}$..60 $\frac{\text{lb}}{\text{in}^2}$..9.2 $\frac{\text{lb}}{\text{in}^2}$..

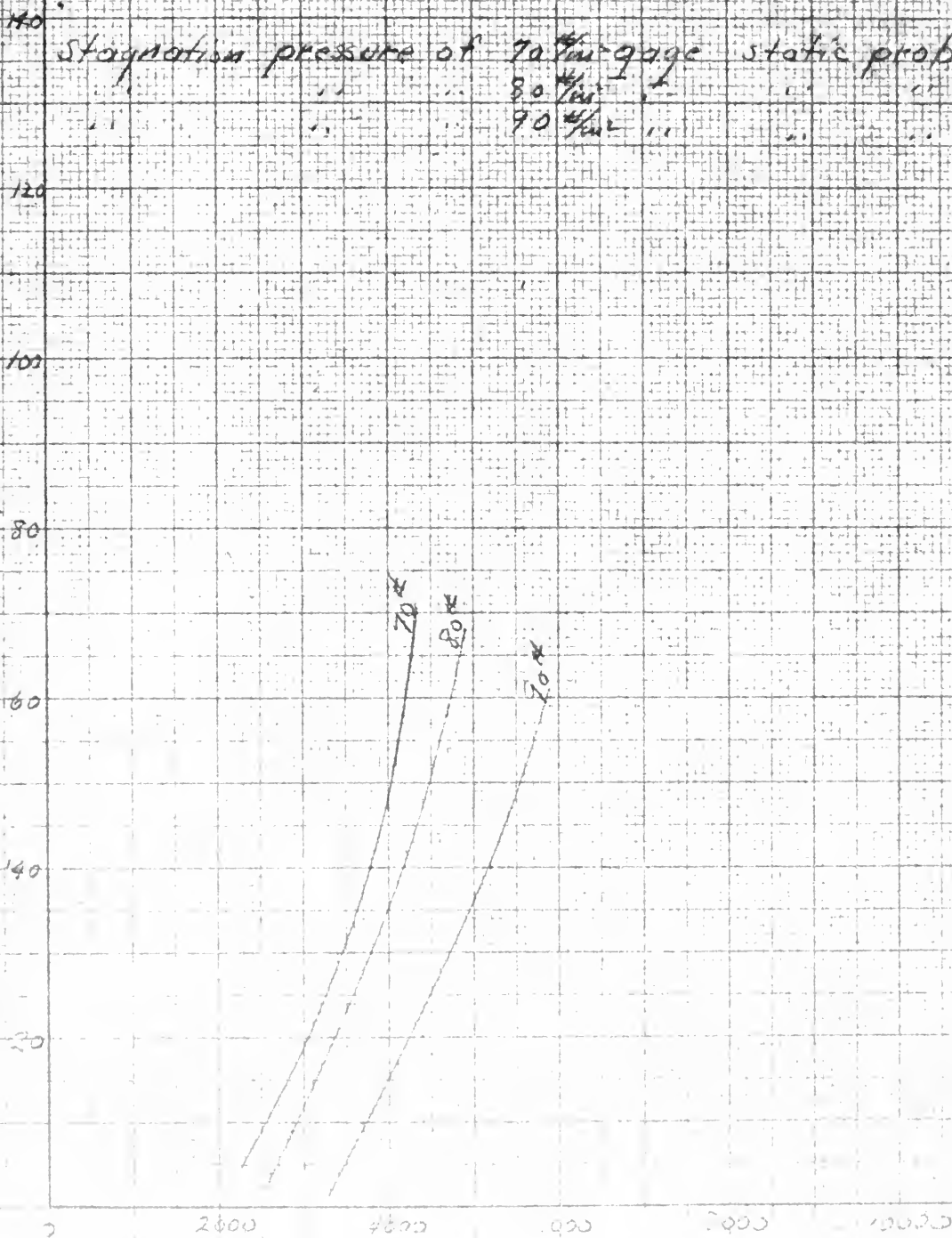
Fig-17-

Microamps VS Volts

Wick, 1003 platinum
spacing 12.5
Wick number 2.81
position in nozzle 3"

Stagnation pressure of 70th gage static probe 11.7 ^{psi}/_{in} gage
80th " " " " 11.0 ^{psi}/_{in} " "
90th " " " " 10.2 ^{psi}/_{in} " "

Microamps



Volts

Fig-1B-

Microamps Vs Volts

Wire .003 platinum
Spacing .125
Mach number - 3.1
position in nozzle 4"

Stagnation pressure of 90 $\frac{\text{lb}}{\text{in}^2}$ static probe 12.4 $\frac{\text{lb}}{\text{in}^2}$
 " " " 94 $\frac{\text{lb}}{\text{in}^2}$ " " 12.1 $\frac{\text{lb}}{\text{in}^2}$
 " " " 100 $\frac{\text{lb}}{\text{in}^2}$ " " 11.87 $\frac{\text{lb}}{\text{in}^2}$

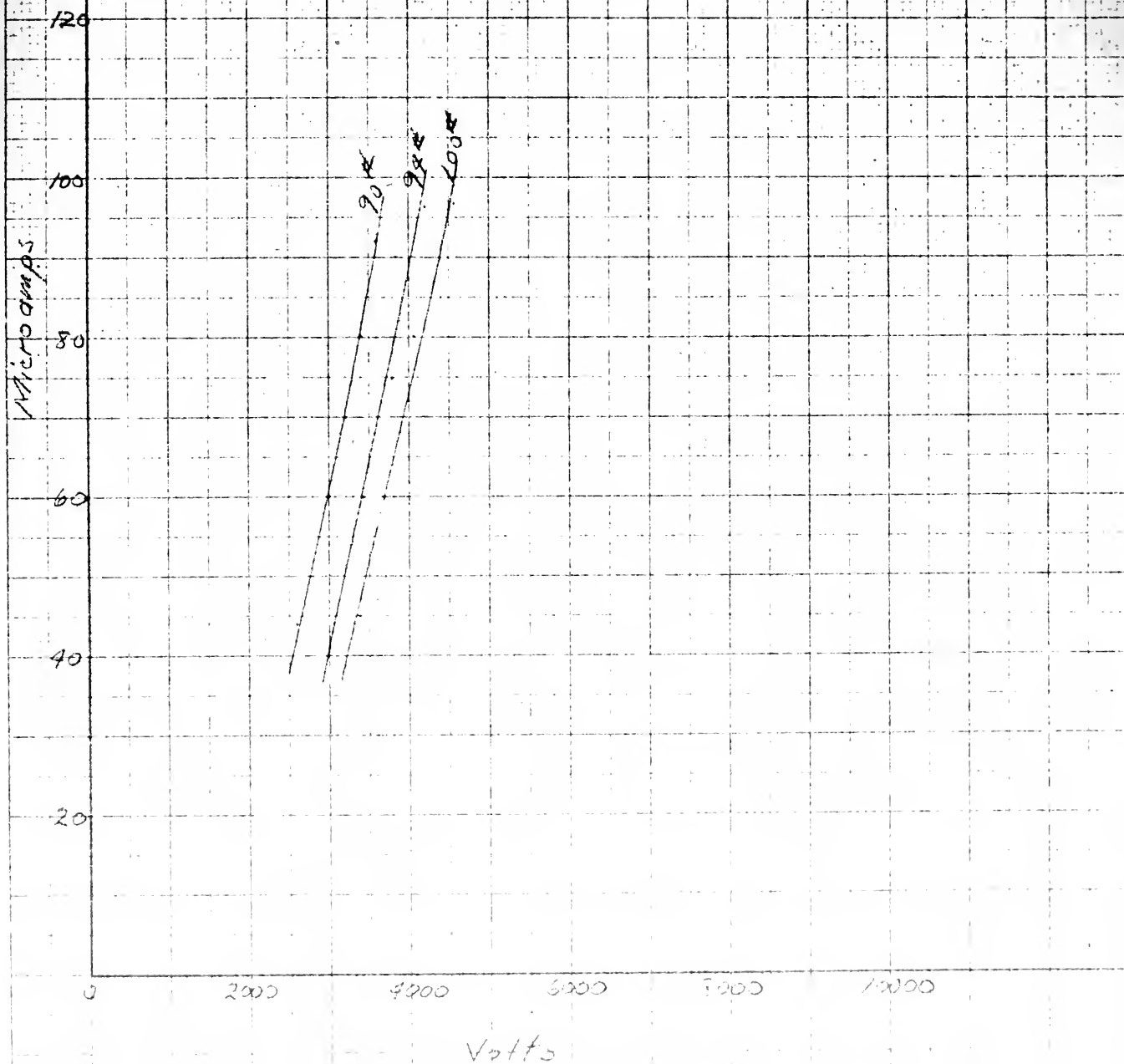


Fig-19-



absolute pressure vs Volts

Mach number = 2.08
 Spacing = .125 inches
 Wire = .003 platinum

absolute pressure inches hg

1000g

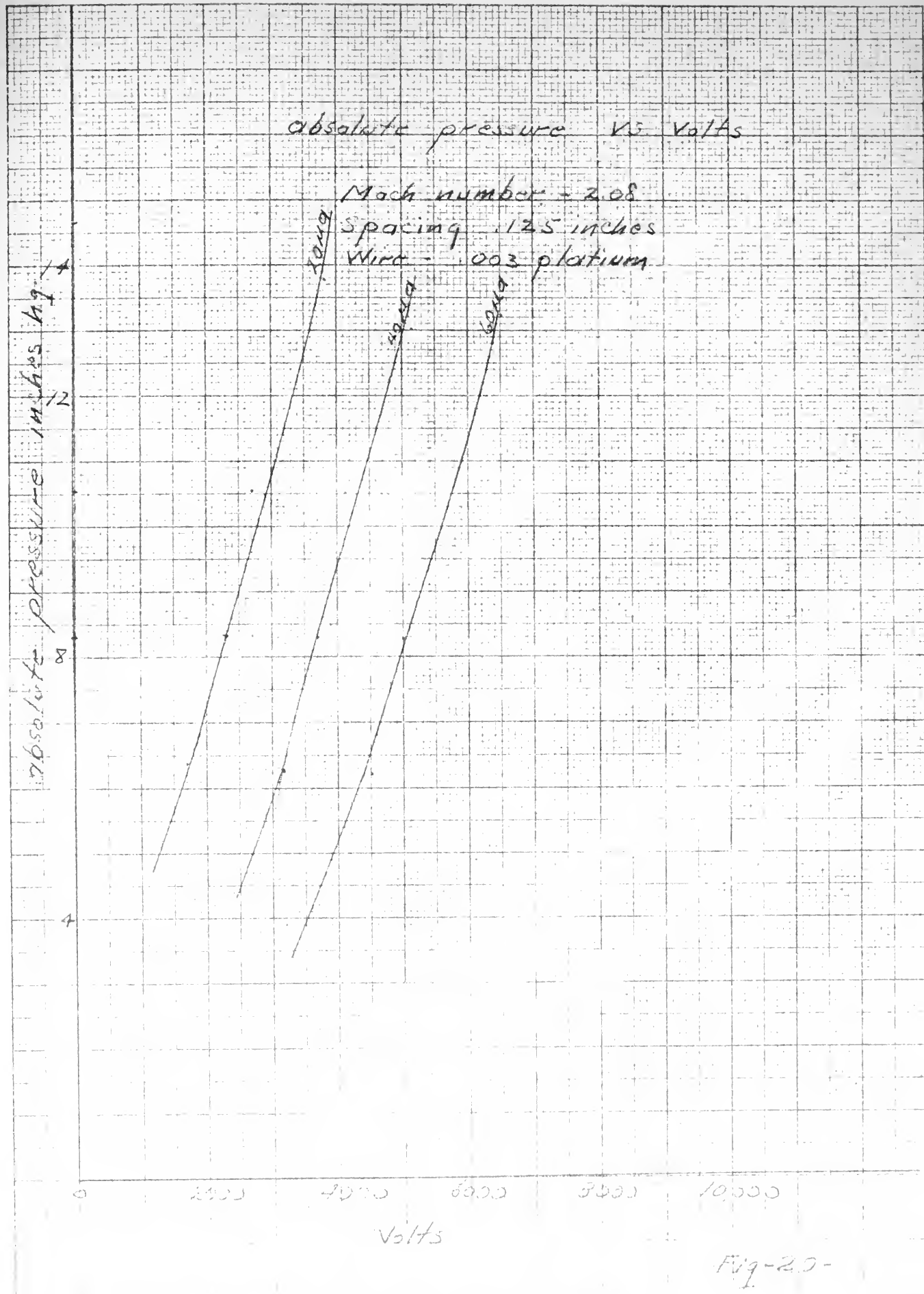
4000g

6000g

0 2000 4000 6000 8000 10000

Volts

Fig-2.0-





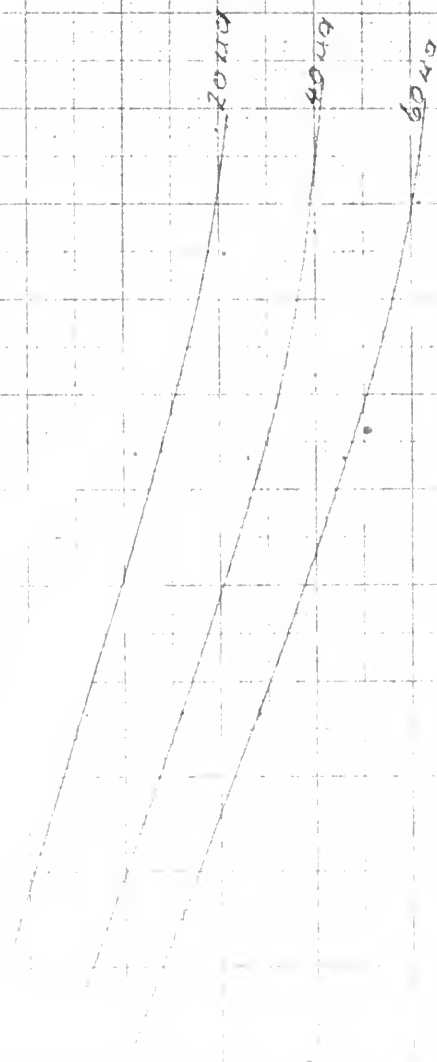
absolute pressure vs Volts

Mach number 2.44

Spacing .125 inches

Wire L. 003 platinum

absolute pressure inches Hg.



absolute pressure Vs Volts

Mach number 2.81

Spacing .125 inches

Wire .003 platinum

absolute pressure inches Hg

14

12

8

4

5000

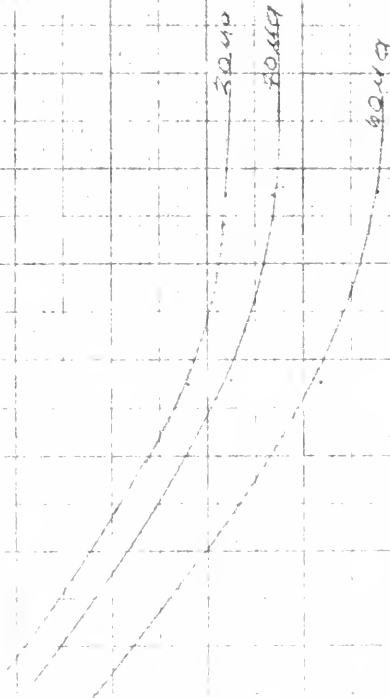
4000

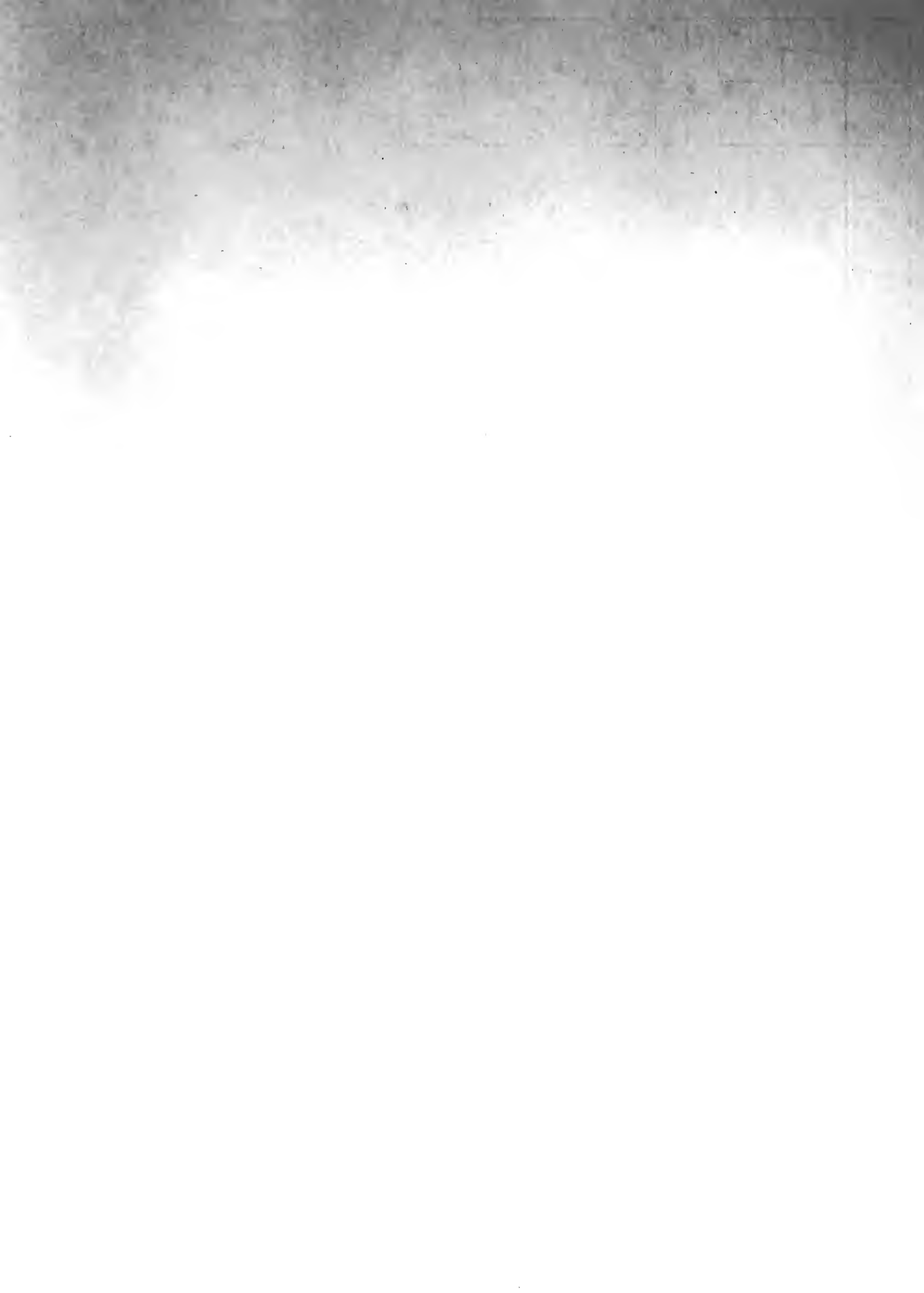
3000

0 2000 4000 6000 8000 10000

Volts

10-23





absolute pressure vs volts

Mach number 3.1
Spacing .125 inches
Wire .005 platinum

absolute pressure in inches Hg

14

12

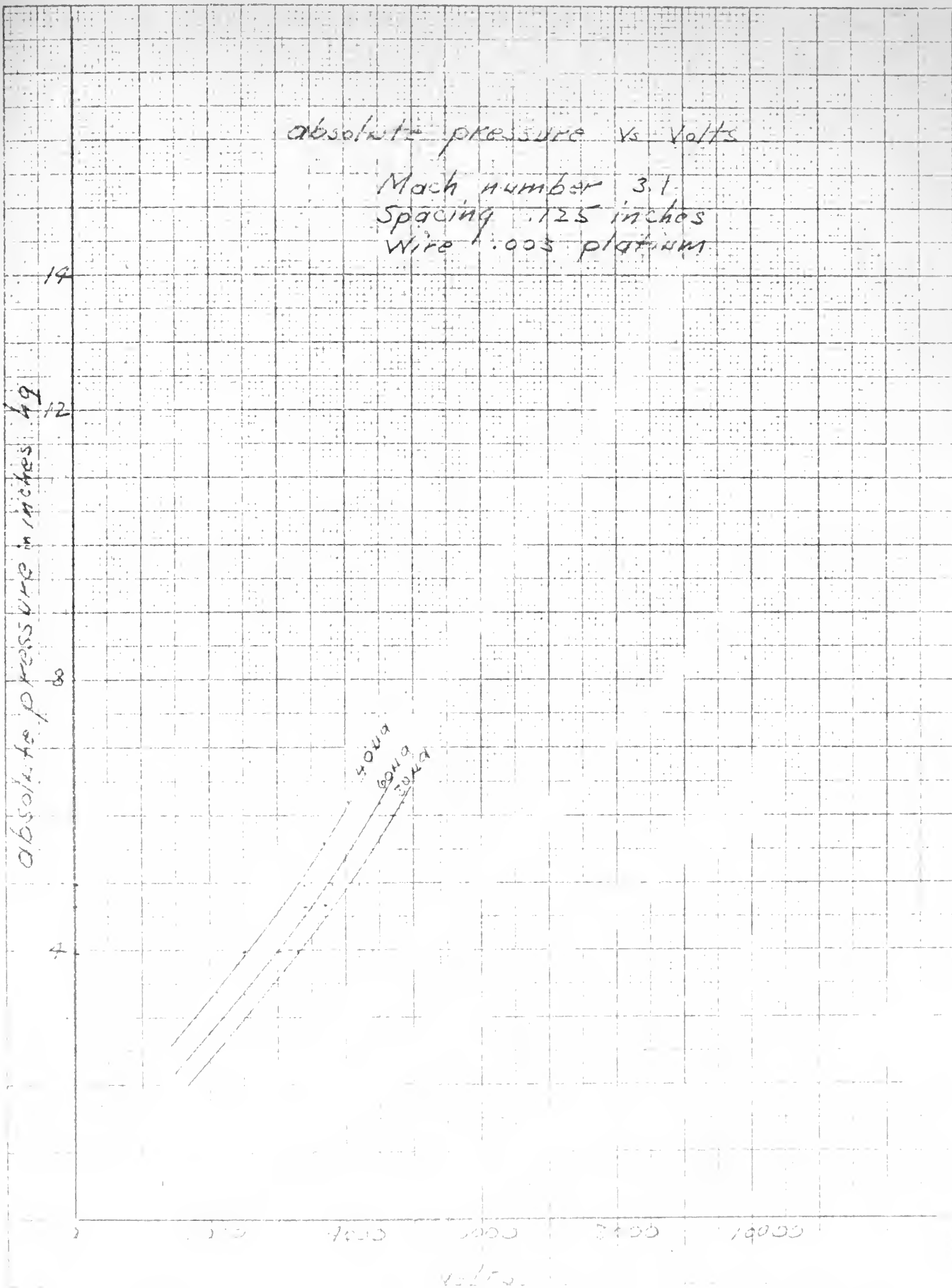
8

4

40V
60V
100V

volts

Fig-23-



Microamps vs Volts at const. abs. Pressure
absolute pressure = 5 inches hg.

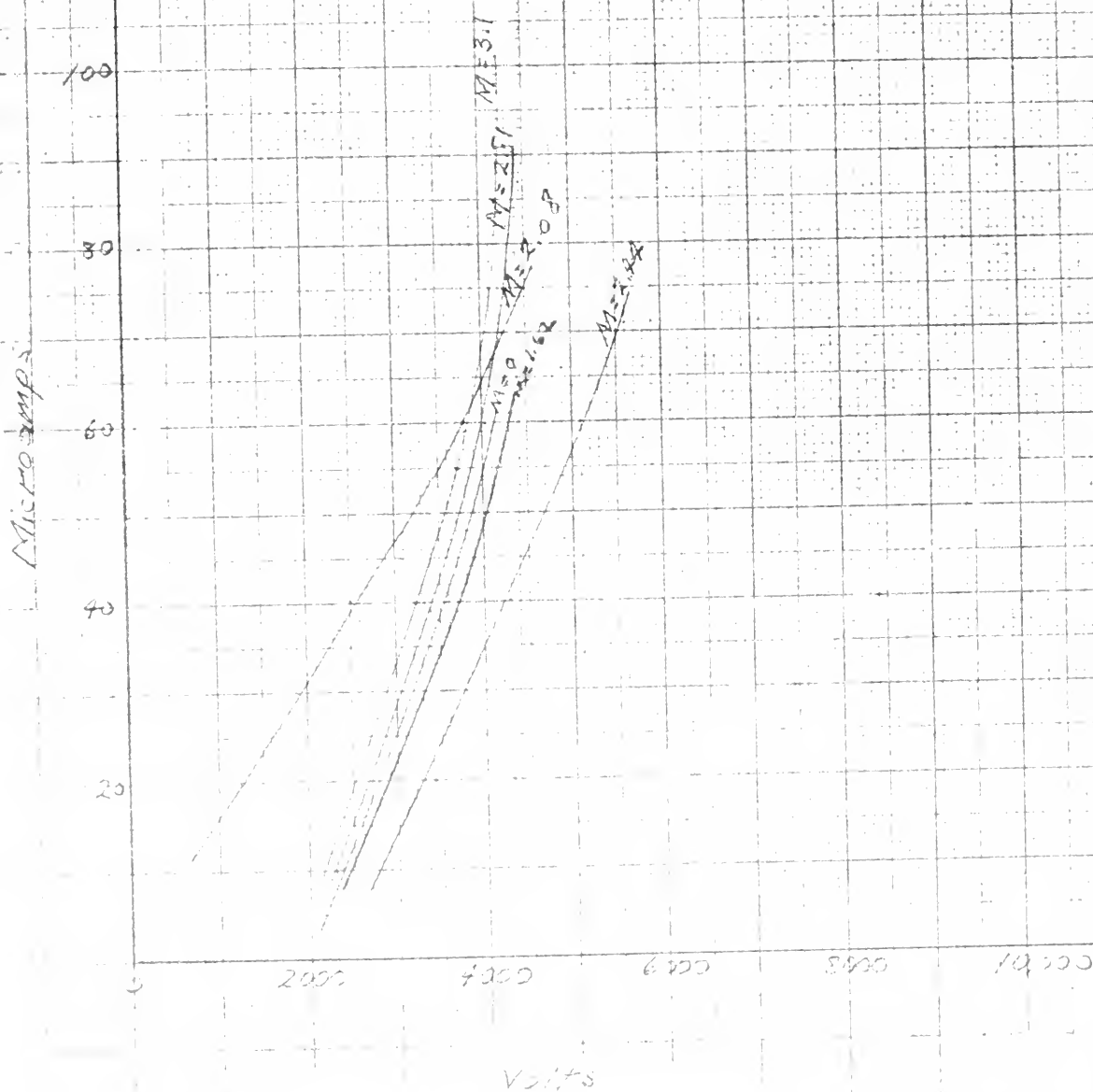
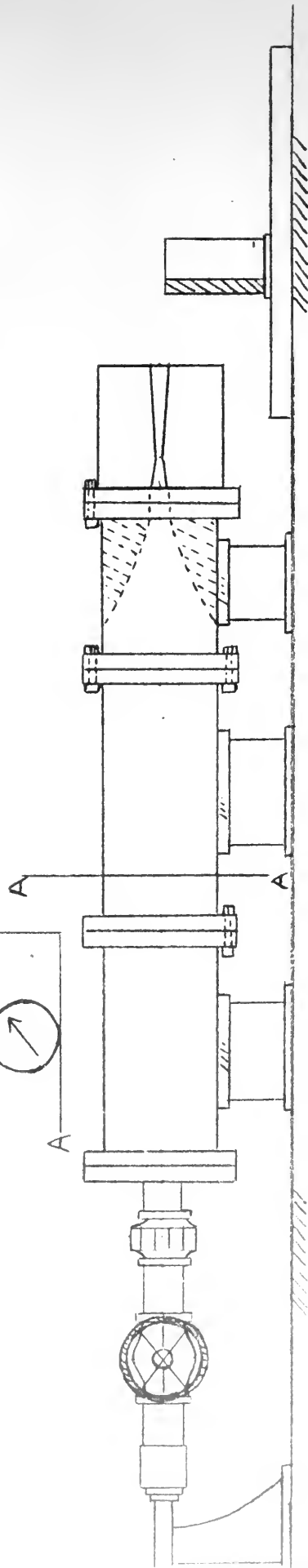
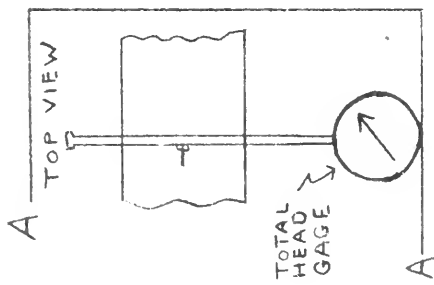


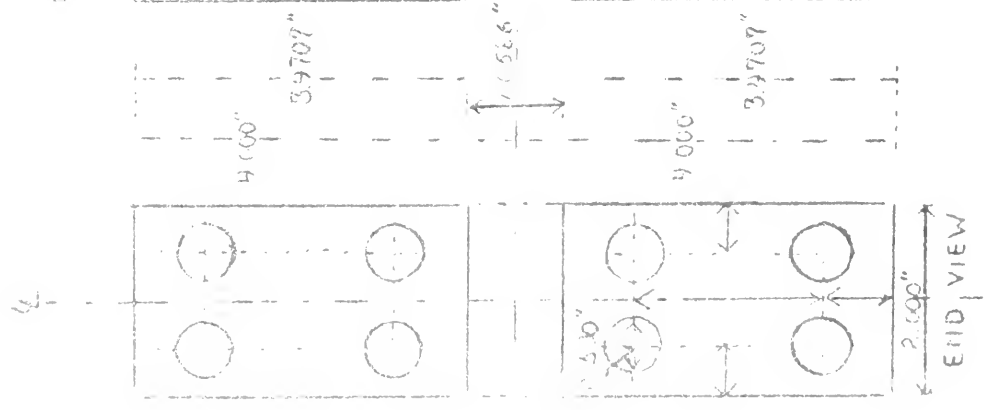
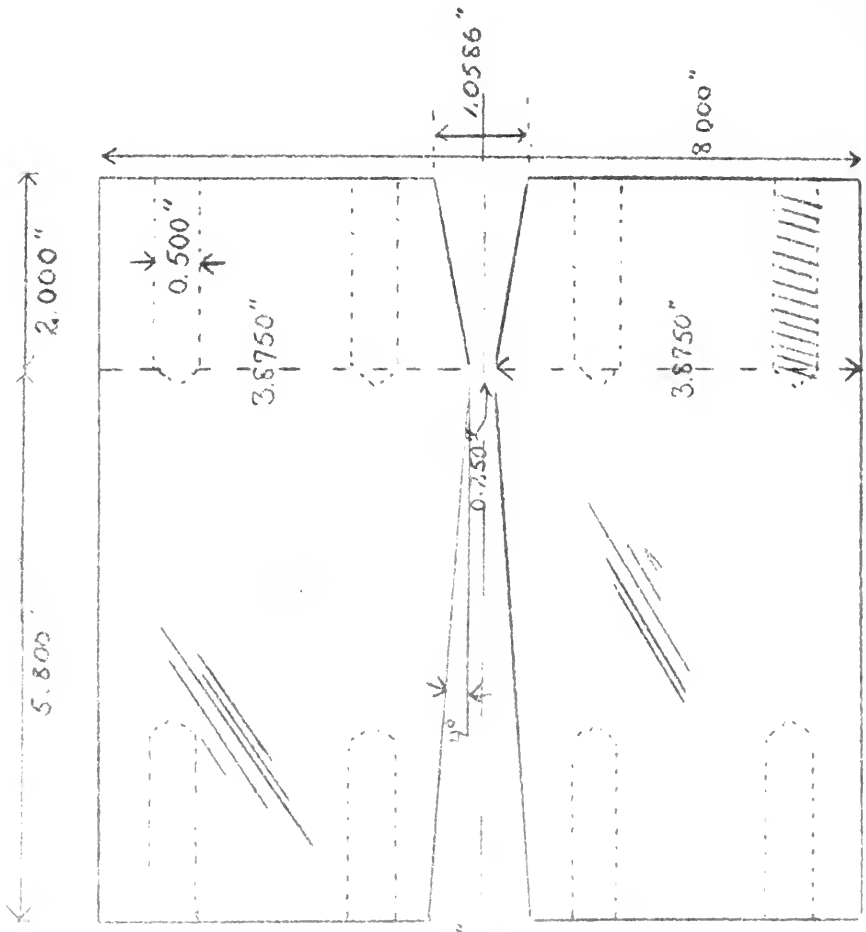
Fig-24-

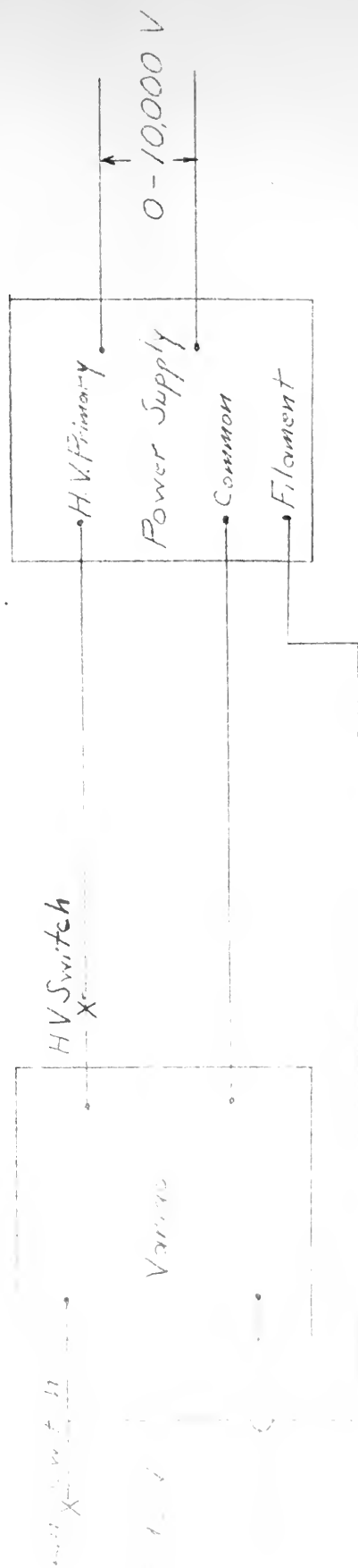


SCALE $\frac{1}{10}'' = 1''$

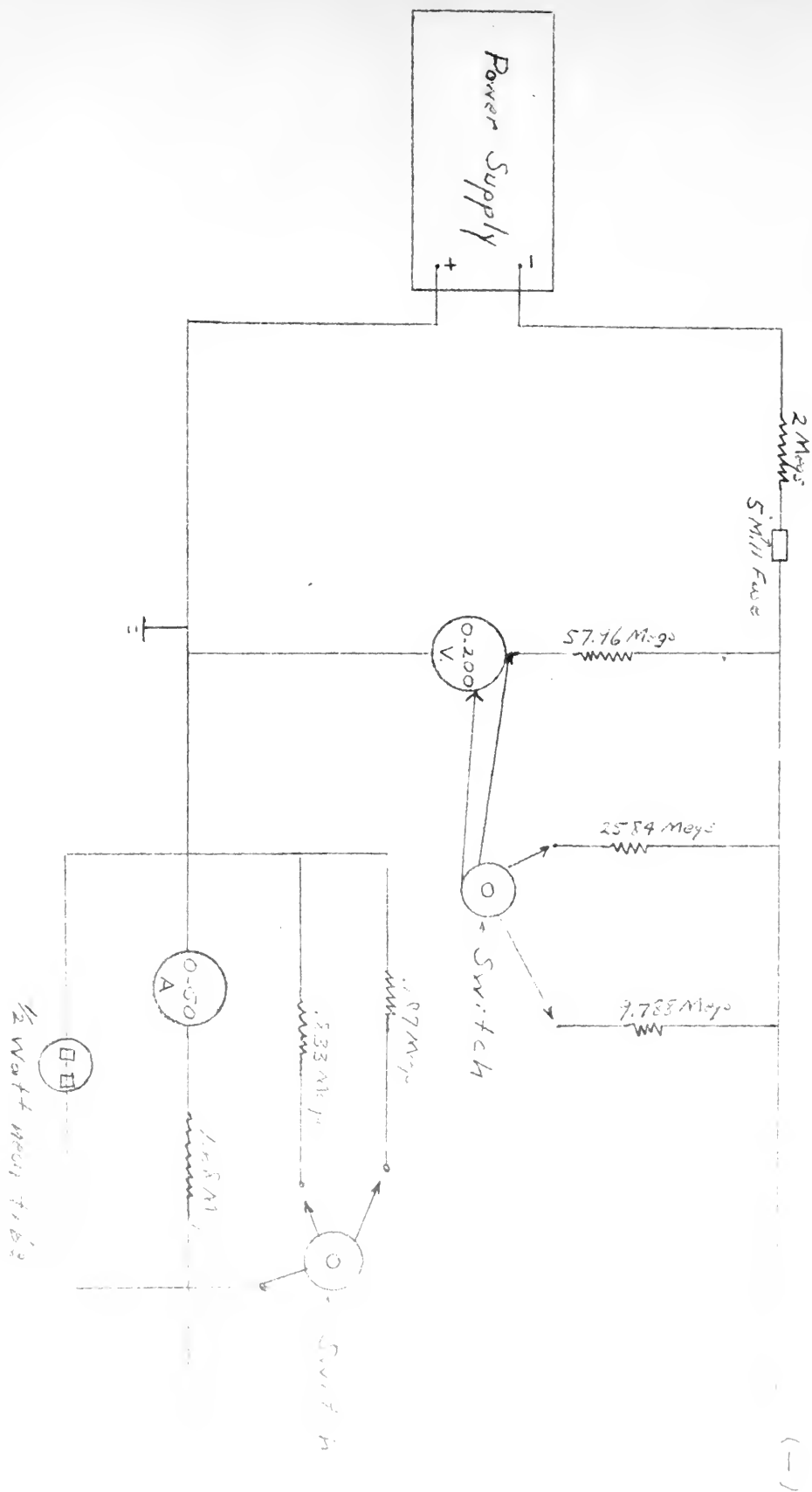
SIDE VIEW
WIND TUNNEL

NOZZLE BLOCK DESIGN



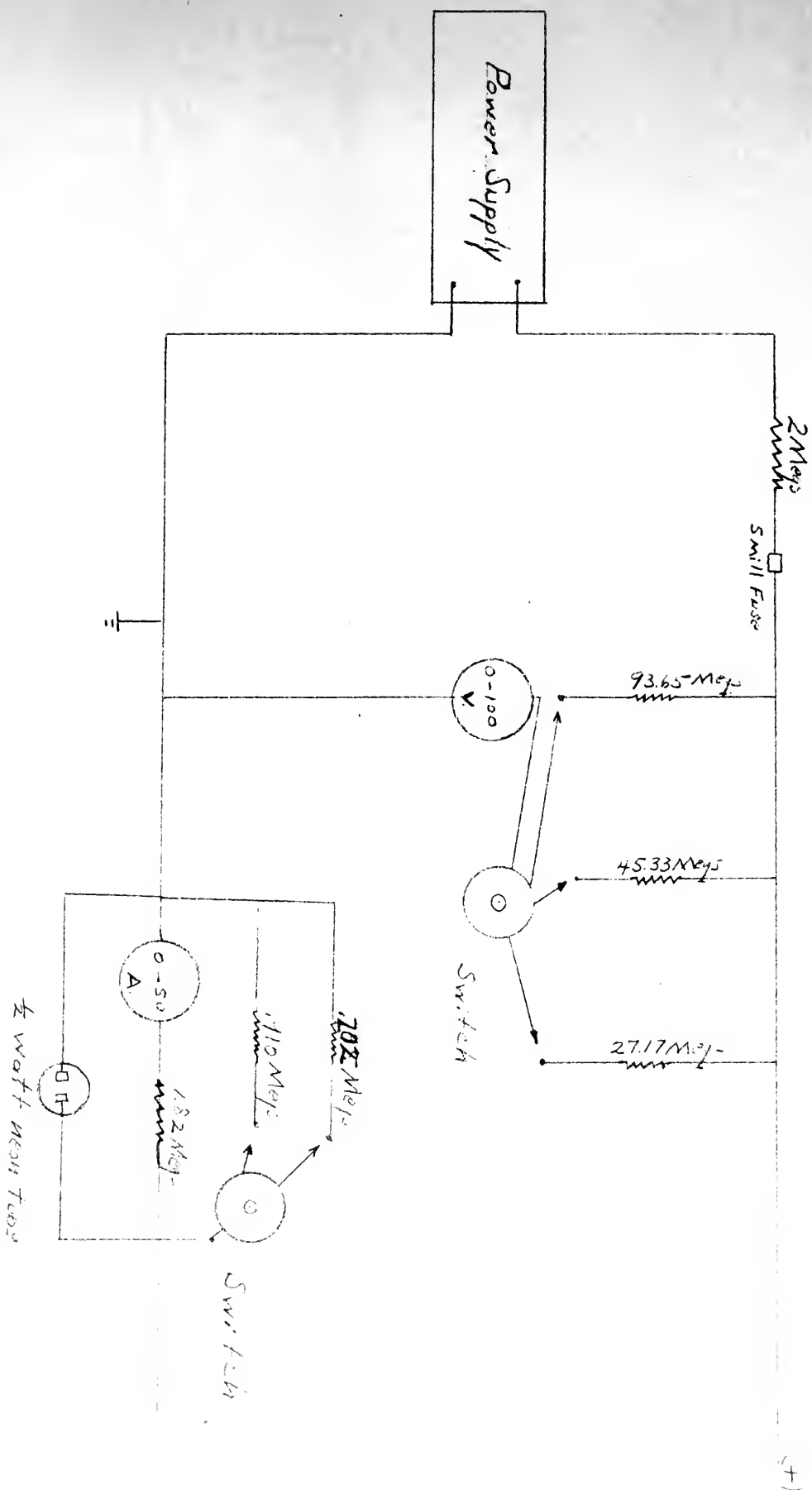


Power Supply



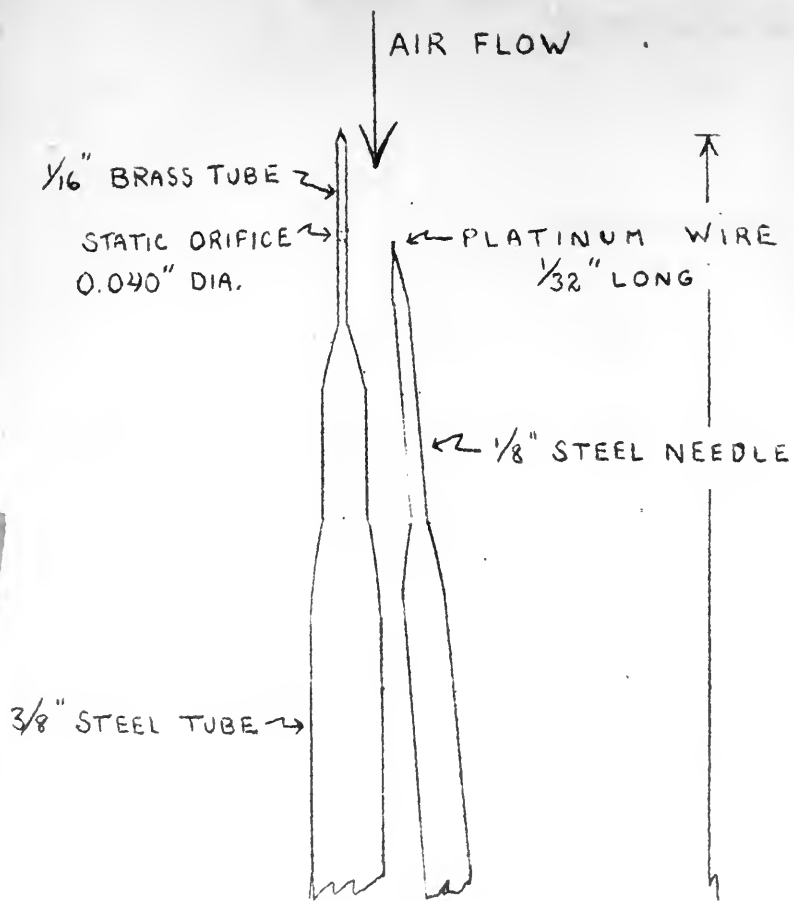
Circuit # 1



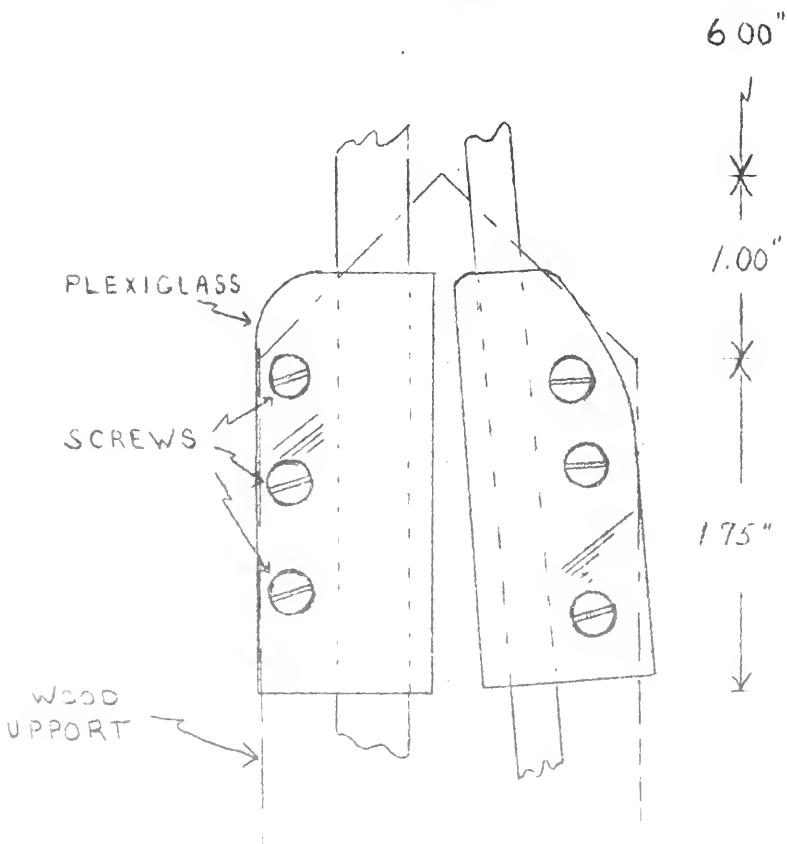


Circuit

2

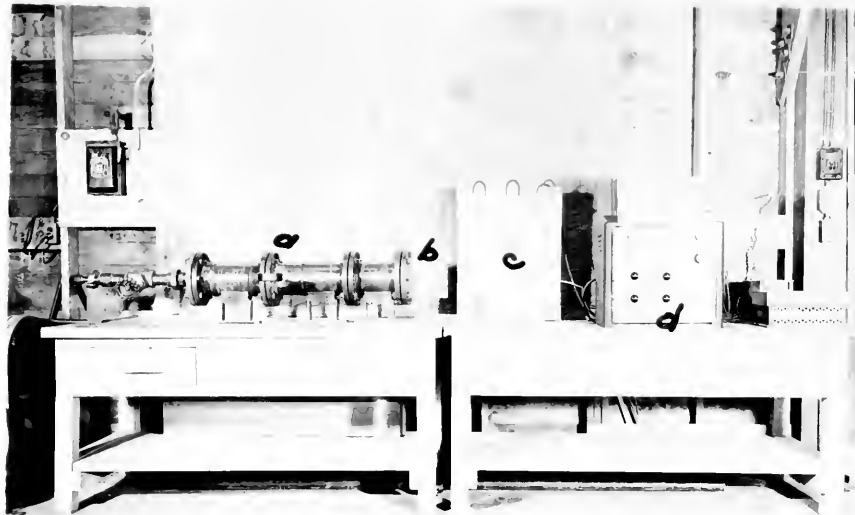


ARRANGEMENT of the PROBES





WIND TUNNEL & ELECTRONIC EQUIPMENT



- a - Stagnation Chamber
- b - Nozzle
- c - Manometer Board
- d - Electronic Equipment

Fig. 31

WIND TUNNEL & ELECTRONIC EQUIPMENT

1960-1961	1962-1963	1964-1965	1966-1967
1968-1969	1970-1971	1972-1973	1974-1975
1976-1977	1978-1979	1980-1981	1982-1983
1984-1985	1986-1987	1988-1989	1990-1991
1992-1993	1994-1995	1996-1997	1998-1999
2000-2001	2002-2003	2004-2005	2006-2007
2008-2009	2010-2011	2012-2013	2014-2015
2016-2017	2018-2019	2020-2021	2022-2023
2024-2025	2026-2027	2028-2029	2030-2031
2032-2033	2034-2035	2036-2037	2038-2039
2040-2041	2042-2043	2044-2045	2046-2047
2048-2049	2050-2051	2052-2053	2054-2055
2056-2057	2058-2059	2060-2061	2062-2063
2064-2065	2066-2067	2068-2069	2070-2071
2072-2073	2074-2075	2076-2077	2078-2079
2080-2081	2082-2083	2084-2085	2086-2087
2088-2089	2090-2091	2092-2093	2094-2095
2096-2097	2098-2099	2100-2101	2102-2103
2104-2105	2106-2107	2108-2109	2110-2111
2112-2113	2114-2115	2116-2117	2118-2119
2120-2121	2122-2123	2124-2125	2126-2127
2128-2129	2130-2131	2132-2133	2134-2135
2136-2137	2138-2139	2140-2141	2142-2143
2144-2145	2146-2147	2148-2149	2150-2151
2152-2153	2154-2155	2156-2157	2158-2159
2160-2161	2162-2163	2164-2165	2166-2167
2168-2169	2170-2171	2172-2173	2174-2175
2176-2177	2178-2179	2180-2181	2182-2183
2184-2185	2186-2187	2188-2189	2190-2191
2192-2193	2194-2195	2196-2197	2198-2199
2200-2201	2202-2203	2204-2205	2206-2207
2208-2209	2210-2211	2212-2213	2214-2215
2216-2217	2218-2219	2220-2221	2222-2223
2224-2225	2226-2227	2228-2229	2230-2231
2232-2233	2234-2235	2236-2237	2238-2239
2240-2241	2242-2243	2244-2245	2246-2247
2248-2249	2250-2251	2252-2253	2254-2255
2256-2257	2258-2259	2260-2261	2262-2263
2264-2265	2266-2267	2268-2269	2270-2271
2272-2273	2274-2275	2276-2277	2278-2279
2280-2281	2282-2283	2284-2285	2286-2287
2288-2289	2290-2291	2292-2293	2294-2295
2296-2297	2298-2299	2300-2301	2302-2303
2304-2305	2306-2307	2308-2309	2310-2311
2312-2313	2314-2315	2316-2317	2318-2319
2320-2321	2322-2323	2324-2325	2326-2327
2328-2329	2330-2331	2332-2333	2334-2335
2336-2337	2338-2339	2340-2341	2342-2343
2344-2345	2346-2347	2348-2349	2350-2351
2352-2353	2354-2355	2356-2357	2358-2359
2360-2361	2362-2363	2364-2365	2366-2367
2368-2369	2370-2371	2372-2373	2374-2375
2376-2377	2378-2379	2380-2381	2382-2383
2384-2385	2386-2387	2388-2389	2390-2391
2392-2393	2394-2395	2396-2397	2398-2399
2400-2401	2402-2403	2404-2405	2406-2407
2408-2409	2410-2411	2412-2413	2414-2415
2416-2417	2418-2419	2420-2421	2422-2423
2424-2425	2426-2427	2428-2429	2430-2431
2432-2433	2434-2435	2436-2437	2438-2439
2440-2441	2442-2443	2444-2445	2446-2447

NOZZLE, BLOCKS, PROBES & VACUUM JAR



Fig. 32

MOBILE, BLOOMING, PROPER & VACUUM JAR



Static Probe

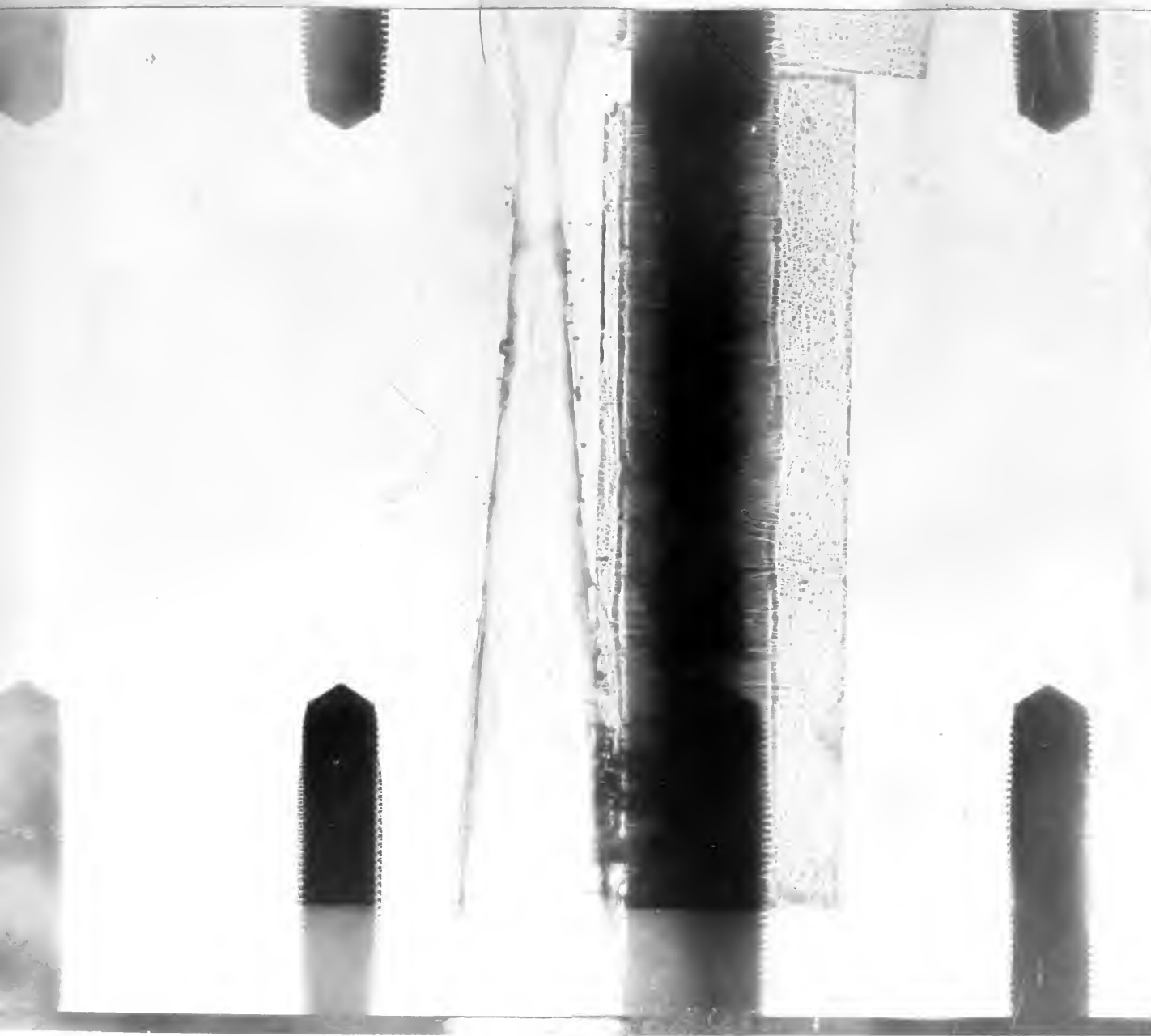
Platinum Wire
Probe

PROBES, SPARK PHOTOGRAPH

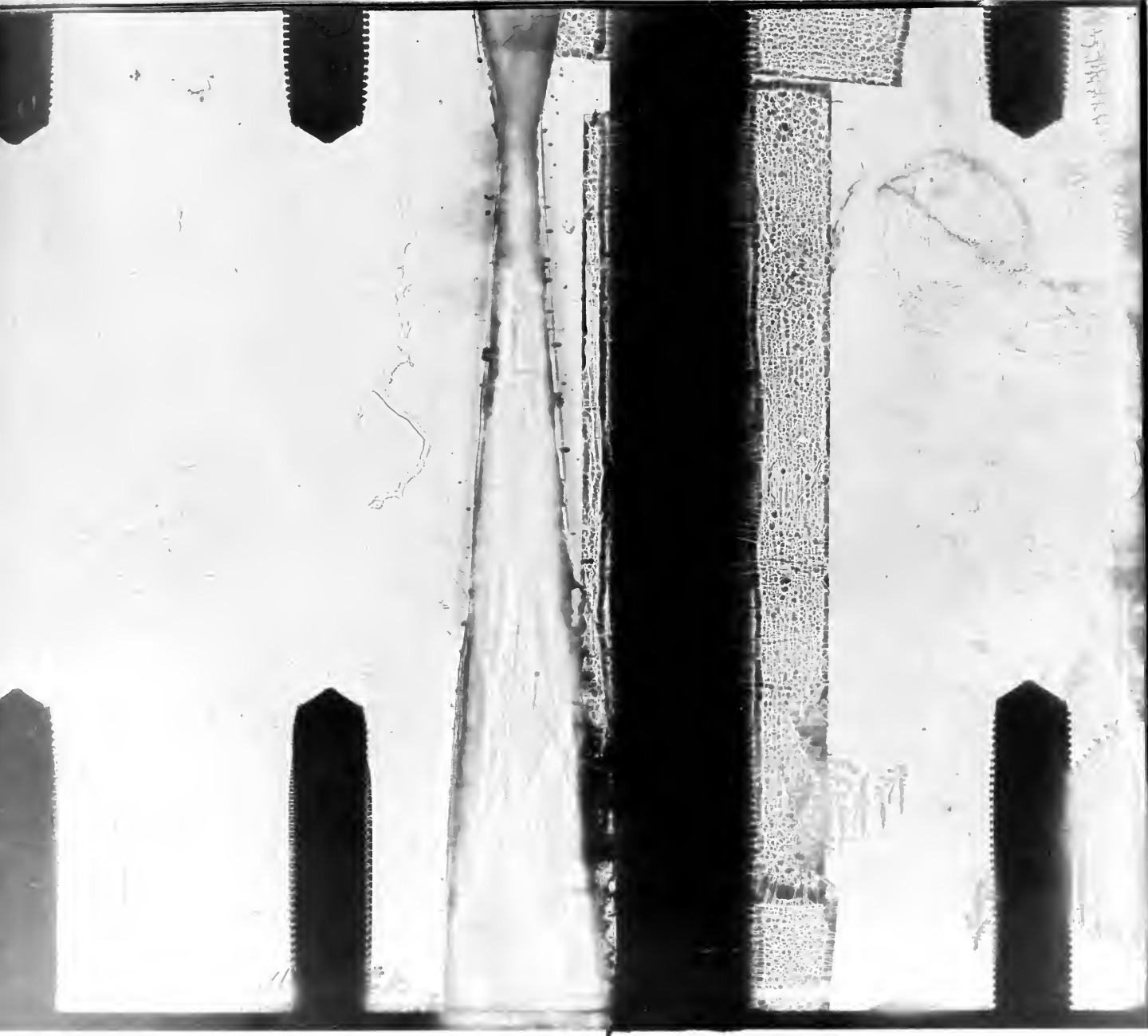
Static Probe

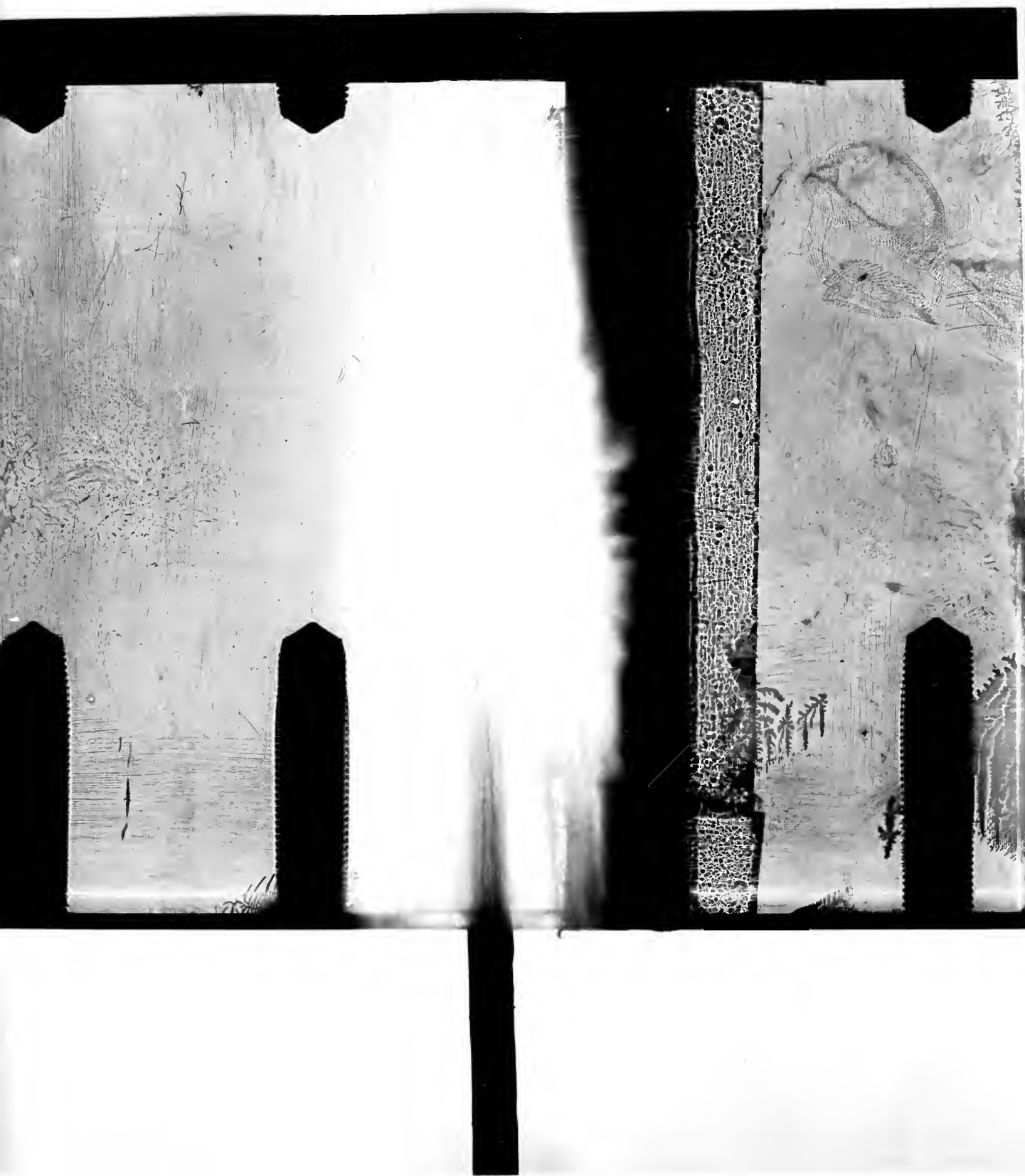
Plexus Wire
Probe

STATIONARY WIRE, GEORGE









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